VUV Ring Report

Stephen Kramer
VUV Ring Manager

The VUV ring operating statistics for the Fiscal Year 2000 are presented in Figure 1. A breakdown of the most significant operational performance statistics is presented in Figures 2 through 6. The operational reliability, 98.8%, shows a significant increase from the lower values of the past few years. However, the total users beam time provided exceeded the scheduled time by almost 2%. The major causes of this unscheduled downtime were: a leak in a ceramic gap for the injection kicker, RF system problems and power problems with the Superconducting Magnetic Energy Storage (SMES) device. The leaking ceramic gap has been sealed and is scheduled for replacement during the Winter shutdown 2000-01. The RF systems had two tubes replaced in FY'00 and also a temperature controller. The SMES trailer has had considerable problems this past year with compressors and cooling systems being replaced. Most of this work was completed without interruption to the schedule but sometimes when faults occurred that were not easily reset, preventing the VUV ring from being restarted without the SMES device online. Although this system is on maintenance contract, special thanks are due Joe Sheehan, who has worked very hard coordinating the repair of this system under difficult circumstances.

The VUV ring has continued to run quite well, with a record total hours of operation almost 67% of the year. The users asked for operational fills up to 1 Ampere, but this was cut back to 850mA after the ceramic gap started to leak. Lifetime continues to be about 17% lower that the peak values obtained in 1997, but this hasn't caused any problem for the users. Injection rates have decreased slightly, but injections still are less than 3 minutes on average.

The major improvement to the VUV ring this year was the development of the new Digital Orbit Feedback System (DOFS). Boris Podobedov led this effort, which has been extremely useful in providing improved orbit stability. This system uses all pickups (instead of only 8 in the Global Orbit Feedback System) and the same 8 trim magnets (the additional 8 trims don't have the necessary frequency response). The DOFS updates the orbit reading at a 5KHz rate and allows flexible filtering of the orbit readings in time as well as azimuth. Being digital, as compared to the older analog system, this gives greater flexibility in changing the configuration. This already has proved its worth, when a BPM receiver failed. The operator disabled the input and returned to operations in a very short time. The offending receiver was then replaced when the technician was available and the DOFS was returned to normal operations at the next fill. Work will continue on this system, in order to better damp beam motion at 60 Hz.

Work has continued on damping the vibration of individual mechanical vacuum pumps on the experimental floor. This work started more than a year ago when the FTIR beam lines showed sensitivity to local vibrations. This work will hopefully reduce the impact of these sources and minimize the impact of new mechanical vibration sources, as they are added to the VUV floor.

During the May shutdown, it was found that the two strip-line kickers used to damp longitudinal beam motion were not working properly. They are scheduled to be replaced during the winter shutdown. When these are replaced the longitudinal damping system should help to suppress the large amplitude dipole oscillations that presently limit operations for timing experiments to less than 50 mA. The bunch stretching RF cavity damps this instability for normal operations. However, timing experiments want shorter bunches requiring this cavity to be turned off or to reverse its effect on the bunch length. During the winter shutdown, there will be an effort to understand the status of the damping antennae in the main RF cavity, to see if they are contributing to this problem.

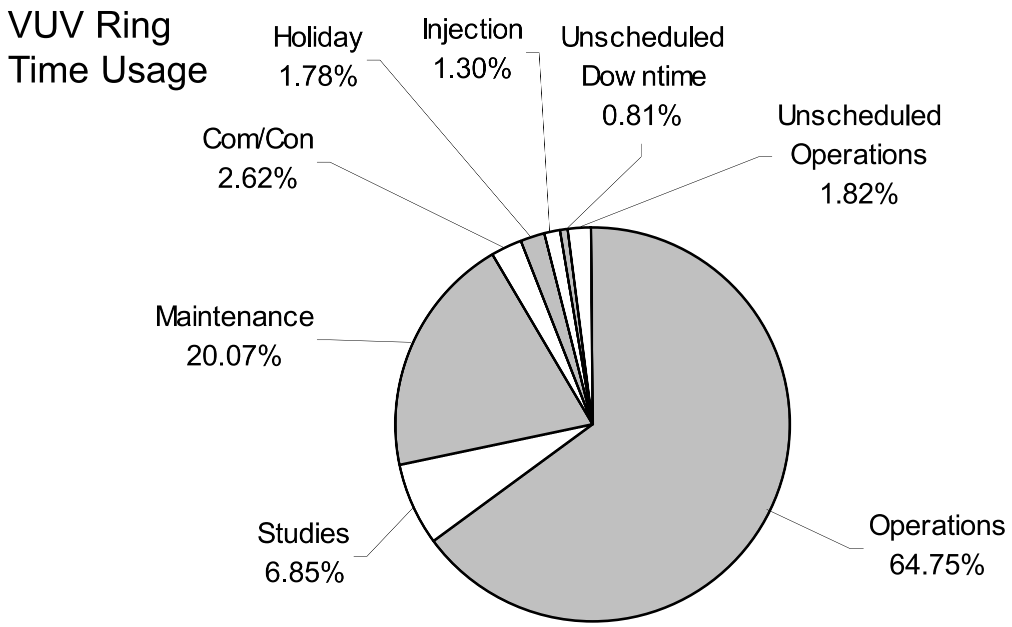


Figure 1: The breakdown of the VUV Ring usage based on calendar time (not scheduled time)

FY 2000 Ring Performance Statistics

Ave. fill Current: 917 mA
Ave. Charge Rate: 131 mA/min
Ave. Lifetime at 500 mA: 308 min
Total user integrated current:
3270 A-Hrs (136 A-days)
Total hours of operation: 5848 hours
Average operating current: 560 mA

VUV Ring Performance

2000

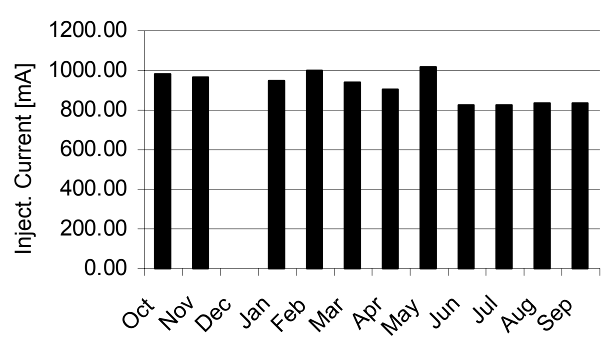


Figure 4: The injection current averaged over all fills in a month for the VUV Ring.

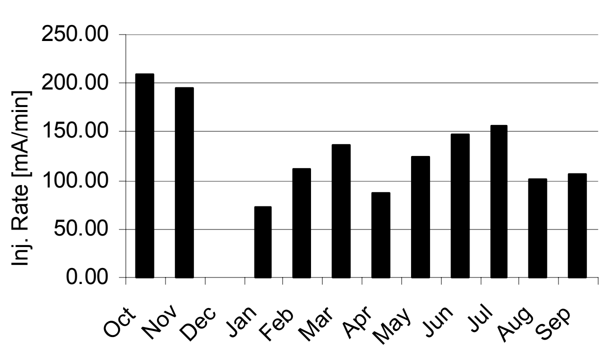


Figure 2: The VUV Ring Injection charge rate average over all fills in each month.

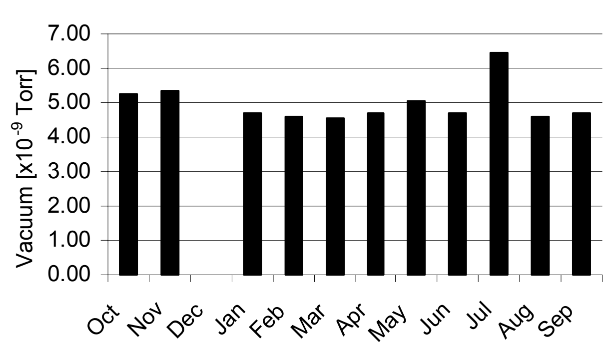


Figure 5: The VUV Ring vacuum pressure at 500 mA beam current averaged over each month.

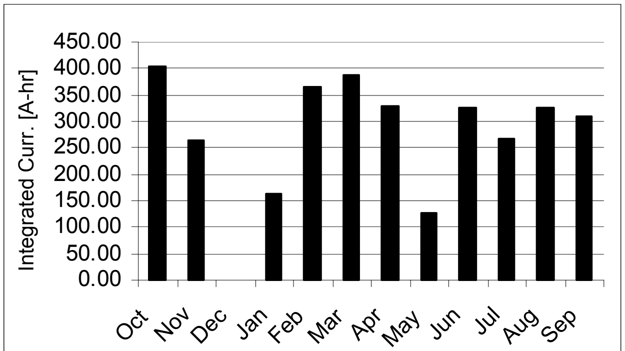


Figure 3: The total integrated current for the VUV Ring accumulated each month.

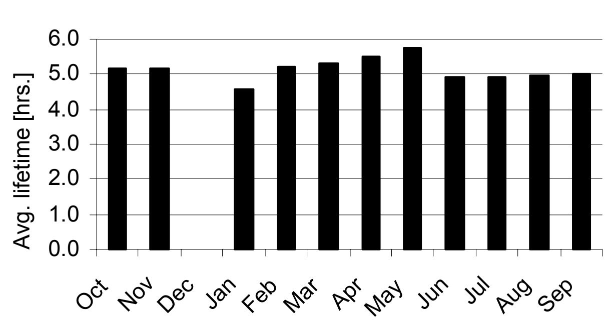


Figure 6: The VUV Ring exponential beam lifetime at 500 mA beam current (seven bunch operation only) averaged over each month.

VUV Storage Ring Parameters as of November 2000

Normal Operating Energy	0.808 GeV
Peak Operating Current (multibunch ops.)	1.0 amp (1.06 x 10^{12}e-)
Circumference	51.0 meters
Number of Beam Ports on Dipoles	18
Number of Insertion Devices	2
Maximum Length of Insertion Devices	~ 2.25 meters
$\lambda_c(E_c)$	19.9 Å (622 eV)
$B(\rho)$	1.41 Tesla (1.91 meters)
Electron Orbital Period	170.2 nanoseconds
Damping Times	$\tau_x=\tau_y$= 13 msec; τ_ε = 7 msec
Lifetime @ 200 mA with 52 MHz	360 min
(with 211 MHz Bunch Lengthening)	(590 min)
Lattice Structure (Chasman-Green)	Separated Function, Quad, Doublets
Number of Superperiods	4
Magnet Complement	8 Bending (1.5 meters each) 24 Quadrupole (0.3 meters each) 12 Sextupole (0.2 meters each)
Nominal Tunes (ν_x, ν_y)	3.14, 1.26
Momentum Compaction	0.0235
RF Frequency	52.886 MHz
Radiated Power	20.4 kW/amp of Beam
RF Peak Voltage with 52 MHz (with 211 MHz)	80 kV (20kV)
Design RF Power with 52 MHz (with 211 MHz)	50 kW (10 kW)
Synchrotron Tune (ν_s)	0.0018
Natural Energy Spread (σ_e/E)	5.0 x 10^{-4} , I_b< 20 mA
Bunch Length (2σ)	9.7 cm (I_b < 20 mA)
($2L_{rms}$ with 211 MHz Bunch Lengthening)	(36 cm)
Number of RF Buckets	9
Typical Bunch Mode	7
Horizontal Damped Emittance (ε_x)	1.62 x 10^{-7}, meter-radian
Vertical Damped Emittance (ε_y)	≥ 3.5 x 10^{-10} meter-radian (4.0 x 10^{-9} in normal ops.)*
Power per Horizontal Milliradian (1A)	3.2 Watts

Arc Source Parameters

Betatron Function (β_x, β_y)	1.18 to 2.25 m, 10.26 to 14.21 m
Dispersion Function (η_x, η_x)	0.500 to 0.062 m, 0.743 to 0.093 m
$\alpha_{x,y} = -\beta'_{x,y}/2$	-0.046 to 1.087, 3.18 to -0.96
$\gamma_{x,y} = (1 + \alpha_{x,y})/\beta_{x,y}$	0.738 to 0.970 m^{-1}, 1.083 to 0.135 m^{-1}
Source Size (σ_x, σ_y)	536 to 568 µm, >60 to >70 µm (170-200 µm in normal ops.)*
Source Divergence (σ_x, σ_y)	686 to 373 µrad, 19.5 to 6.9 µrad (55-20 µrad in normal ops.)*

Insertion Device Parameters

Betatron Functionµm (β_x, β_y)	11.1 m, 5.84 m
Source Size (σ_x, σ_y)	1240 µm, >45 µm (220 µm in normal ops.)*
Source Divergence (σ_x, σ_y)	112 µrad, >7.7 µrad (22 µrad in normal ops.)*

* ε_y is adjustable

VUV Beamline Upgrades

Steven N. Ehrlich
Beamline Technical Liaison

Beamlines U2A and U3C

There were several beamline technical improvements on the VUV floor during fiscal year 2000. At U2A, an additional microscope system was built inside a new vacuum box adapted to the Bruker IFS66v FTIR spectrometer. It is crucial to remove the vapor absorption bands from the infrared, especially for far-IR, spectra. This system will be the first IR microscope running in the vacuum condition at a VUV ring. At U3C, the monochromator was recalibrated and minor software changes were made.

Beamlines U5UA and U7A

A new branch of beamline U5UA, obtained by refocusing the beam after the endstation, is under design. This branch will allow the simultaneous use of the beamline by two experiments. At U7A, a highly compact electron yield detector with a three-grid electron energy analyzer and ground shield has been designed. Energy resolving electron yield is essential for enhancing and defining the surface sensitivity of their NEXAFS measurements. Additionally, the new detector translates towards the sample to optimize the solid angle of electron collection. There is a new precision grating drive for the U7A monochromator, which improves the speed and reliability in energy position of the grating. An onboard optical encoder and improved general rigidity and reproducibility of a new state of the art linear drive have made this possible. They have also instituted continuous oxygen plasma cleaning of the U7A grating. Oxygen gas will be continuously leaked into the grating chamber during operations with beam in order to continuously clean the grating optical surfaces, avoiding the usual carbon contamination. If the idea works, carbon contamination of the gratings will be overcome along with the intensity and normalization problems that currently exist at the carbon edge.

Beamline U9B

At U9B, a new position-sensitive photomultiplier with sensitivity extending to $\approx$ 900 nm in the near-IR is on order. A new Linux data server was acquired and placed in service. A system for stepped flow circular dichroism and fluorescence polarization anisotrophy was designed and the components have been ordered. Operation is expected during FY2001. This is the start of a major upgrade designed to enhance the performance of U9B in the area of Dynamic Structural Biology.

Beamline U10A

At U10A, the Bruker IFS66v/S was upgraded to allow collimated beam to be extracted after the beamsplitter. A new multilayer dielectric beamsplitter (T222) has been purchased; this beamsplitter consists of a thin layer of germanium deposited onto thin Mylar, resulting in a vastly improved low frequency response. Finally, the capability for rotating the optical polarizer while the instrument is under vacuum has been added. This feature may be controlled from the OPUS data acquisition software. At U10B, a new infrared microscope was installed and tested. The Spectra Tech Continumm microscope and Nicolet Magna 860 FTIR permit users to access the near-, mid-, and far-infrared regimes. In addition, the Magna 860 bench has step-scan capabilities, permitting users to perform time-resolved measurements through the microscope as well. In the spring of 2000, General User time (25%) was made available. During FY2000, methods for enhancing the available spatial resolution, such as by near-field techniques, were investigated. In addition, fluorescence-assisted infrared micro-spectroscopy was developed.

Beamlines U12A and U12IR

At U12A, a new chamber has been constructed for performing fluorescence yield soft x-ray absorption experiments in UHV. U12IR replaced the Bruker 113V and lamellar grating interferometer with a single instrument (Sciencetech SPS200). A new spectrometer was interfaced to the beamline during FY1999. Spectrometer commissioning continued into FY2000. Vacuum chambers and a cryogenics system for sample handling are presently under construction.

Beamline U14A

In order to help foster new use of U14A, the original endstation for the beamline was re-installed in the summer of 2000. This endstation, which had been loaned to a laser-photoemission project, provides facilities for photoabsorption and both angle-resolved and angle-integrated photoemission, as well as sample manipulation and preparation.

Beamline U16B

The U16B beamline was operational for all of FY2000, providing higher flux than pre-FY1999 owing to the Codling mirror rotation performed in FY1999. A sign error in the third order coefficients of the polynomials which govern the motions of the gratings, Codling slit, and air bearing was corrected, leading to better calibration of the photon energy. A motion controller (Newport ESP7000 with four axis drivers) was procured at the end of FY2000 as a replacement/upgrade of the U16B motor controller, which is a non-commercial product based on electronics which are no longer available for replacement.

VUV Beamline Guide

Beamline U1A

Affiliations: ExxonMobil Research and Engineering Co. Research/Technique: NEXAFS characterization of catalytic materials and fundamental studies of surface chemistry on model systems. Range: 100-1000EV. Operating beamline. Local contact: Michael Sansone, 631-344-5759, msanson@bnl.gov. Spokesperson: Paul Stevens, 908-730-2584, pasteve@erenj.com. Beam phone: 5501.

Beamline U2A

Affiliations: Carnegie Institute of Washington. Research/Technique: Measurement of far- to near-infrared spectra of a wide variety of materials from ambient to ultrahigh pressures at variable temperatures by coupling synchrotron infrared microspectroscopic techniques with new diamond-anvil cell methods. Range: 800-2200EV. Operating beamline. General user allocation: 25%. Local contact: Zhenxian Liu, 631-209-1966, liu@gl.ciw.edu. Spokesperson: Russell Hemley, 202-686-2410,X2465, hemley@gl.ciw.edu. Beam phone: 5502.

Beamline U2B

Affiliations: Albert Einstein College of Medicine. Research/Technique: IR microscopy, time-resolved infrared spectroscopy, and far-infrared spectroscopy. Range: 20-4000CM-. Operating beamline. General user allocation: 25%. Local contact: Nebojsa Marinkovic, 631-344-3808, marinkov@bnl.gov. Spokesperson: Mark Chance, 718-430-4136/2894, mrc@aecom.yu.edu. Beam phone: 5502.

Beamline U3A

Affiliations: Smithsonian Astrophysical Observatory. Research/Technique: Detector and system calibration, measurement of optical constants spectrometeric properties. Range: 70-2100 EV. Operating beamline. Local contact: Michael Sagurton, 631-344-5708, sagurton@bnl.gov. Spokesperson: Roger Bartlett, 505-667-5923, rbartlett@lanl.gov. Beam phone: 5521.

Beamline U3C

Affiliations: PRT Affiliations: Los Alamos National Laboratory, Sandia National Laboratory, SFA, Inc. Research/Technique: Photoelectron spect., experimental system calibrations, and detector calibrations. Range: 40-1600 EV. Operating beamline. General user allocation: 25%. Local contact: Michael Sagurton, 631-344-5708, sagurton@bnl.gov. Spokesperson: Roger Bartlett, 505-667-5923, rbartlett@lanl.gov. Beam phone: 5503.

Beamline U4A

Affiliations: Boston University, Brookhaven National Laboratory/NSLS, North Carolina State University, Rutgers University. Research/Technique: Photoemission spectroscopy in the study of electronic structures in solids and on surfaces. Range: TGM. Operating beamline. General user allocation: 35%. Spokesperson: Kevin Smith, 617-353-6117, ksmith@buphy.bu.edu. Beam phone: 5504.

Beamline U4B

Affiliations: Brookhaven National Laboratory/NSLS, Naval Research Laboratory, Synchrotron Radiation Research Center. Research/Technique: Soft x-ray and VUV, photoemission, spectroscopy and photo absorption. Range: 80-1200 EV. Operating beamline. General user allocation: 35%. Local contact: Shane Stadler, 631-344-5135, stadler@bnlls3.nsls.bnl.gov. Spokesperson: Yves Idzerda, 406-994-7838, idzerda@physics.montana.edu. Beam phone: 7290.

Beamline U5

Affiliations: Brookhaven National Laboratory/NSLS. Research/Technique: Monitoring of beam parameters during operations and machine studies. Diagnostic beamline. Local contact: Nathan Towne, 631-344-7335, towne@bnl.gov. Spokesperson: Nathan Towne, 631-344-7335, towne@bnl.gov. Beam phone: 5505.

Beamline U5UA

Affiliations: Argonne National Laboratory, Brookhaven National Laboratory/NSLS, Physics, University of Texas. Research/Technique: Spin polarized angle-resolved ultraviolet photoemission. Range: TGM. Operating beamline. General user allocation: 50%. Local contact: Elio Vescovo, 631-344-7399, vescovo@bnl.gov. Spokesperson: Elio Vescovo, 631-344-7399, vescovo@bnl.gov. Beam phone: 5505.

Beamline U7A

Affiliations: Brookhaven National Laboratory/Physics, Brookhaven National Laboratory/Chemistry, Dow Chemical Company, National Institute of Standards & Technology, Rutgers University, Texas A&M University, University of Michigan. Research/Technique: XPS and XAS on surface and in bulk, under vacuum and atm.P. Range: TGM. Operating beamline. General user allocation: 25%. Local contact: Qing-Li Dong, 631-344-5358, dong@bnlls1.nsls.bnl.gov. Spokesperson: Daniel Fischer, 631-344-5177, dfischer@bnl.gov. Beam phone: 5507.

Beamline U7B

Affiliations: Brookhaven National Laboratory/NSLS. Research/Technique: Photoemission, SEXAFS. Range: PGM. Operating beamline. General user allocation: 100%. Local contact: Qing-Li Dong, 631-344-5358, dong@bnlls1.nsls.bnl.gov. Spokesperson: Steven Hulbert, 631-344-7570, hulbert1@bnl.gov. Beam phone: 5507.

Beamline U8A

Affiliations: University of California @ Riverside. Research/Technique: ARUPS, NEXAFS. Range: TGM. Operating beamline. General user allocation: 25%. Local contact: Jory Yarmoff, 909-787-5336/3537, yarmoff@bnl.gov. Spokesperson: Jory Yarmoff, 909-787-5336/3537, yarmoff@bnl.gov. Beam phone: 5508.

Beamline U8B

Affiliations: IBM Research Division, University of California @ Riverside, University of Michigan. Research/Technique: ARUPS, NEXAFS. Range: TGM. Operating beamline. General user allocation: 25%. Local contact: Sefik Suzer, 734-763-3173, ssuzer@umich.edu. Spokesperson: Mark Banaszak-Holl, 734-763-2283, mbanasza@bnl.gov. Beam phone: 5508.

Beamline U9A

Affiliations: Brookhaven National Laboratory/NSLS. Research/Technique: PSD measurements of UHV materials at room temperature. Range: WHTE.LIGHT. Operating beamline. Local contact: Christopher Lanni, 631-344-4100, lanni@bnl.gov. Spokesperson: Conrad Foerster, 631-344-4754, foerster@bnl.gov. Beam phone: 7766.

Beamline U9B

Affiliations: Brookhaven National Laboratory/Biology. Research/Technique: Absorption, CD, MCD, florescence, phosphorescence spectrocopy, time resolved florescence. Range: 2.1-8.9 EV. Operating beamline. General user allocation: 25%. Local contact: John Sutherland, 631-344-3279, jcs@bnl.gov. Spokesperson: John Sutherland, 631-344-3279, jcs@bnl.gov. Beam phone: 5509.

Beamline U10A

Affiliations: Brookhaven National Laboratory/NSLS, Brookhaven National Laboratory/Physics. Research/Technique: Measurement of Optical Properties, high brightness IR spectroscopy measurements. Range: INFRARED. Operating beamline. General user allocation: 25%. Local contact: Christopher Homes, 631-344-7579, homes@bnl.gov. Spokesperson: G. Lawrence Carr, 631-344-2237, carr@bnl.gov. Beam phone: 5510.

Beamline U10B

Affiliations: Brookhaven National Laboratory/NSLS, Northrop Grumman ATDC. Research/Technique: IR microspect, micro-sampling, imaging of vibrational/chemical spectroscopic features. Range: 5meV-1000. Operating beamline. General user allocation: 50%. Local contact: Lisa Miller, 631-344-2091, lmiller@bnl.gov. Spokesperson: Lisa Miller, 631-344-2091, lmiller@bnl.gov. Beam phone: 5510.

Beamline U11

Affiliations: Brookhaven National Laboratory/DAS, Brookhaven National Laboratory/NSLS, Brookhaven National Laboratory/Biology. Research/Technique: Gas phase photo-ionization and spectroscopy. Range: 5-30 EV. Operating beamline. General user allocation: 25%. Local contact: John Sutherland, 631-344-3279, jcs@bnl.gov. Spokesperson: Bruce Klemm, 631-342-4001, klemm@sun2.bnl.gov. Beam phone: 5511.

Beamline U12A

Affiliations: Brookhaven National Laboratory/NSLS, Oak Ridge National Laboratory. Research/Technique: Soft x-ray photoemission (SXPS), XAS, NEXAFS. Range: 100-800 EV. Operating beamline. General user allocation: 50%. Local contact: Steven Hulbert, 631-344-7570, hulbert1@bnl.gov. Spokesperson: David Mullins, 423-574-2796, mullinsdr@ornl.gov. Beam phone: 5512.

Beamline U12IR

Affiliations: Brookhaven National Laboratory/NSLS, University of Florida. Research/Technique: IR and far-IR measurement time-resolved (pump/probe IR & far-IR spectroscopy). Range: 0.5MEV-1EV. Operating beamline. General user allocation: 25%. Local contact: G. Lawrence Carr, 631-344-2237, carr@bnl.gov. Spokesperson: David Tanner, 352-392-4718, tanner@phys.ufl.edu. Beam phone: 6220.

Beamline U13UA

Affiliations: Brookhaven National Laboratory/NSLS. Research/Technique: High resolution VUV and soft x-ray absorption and electron spectr. (incl. spin-polarized phtoemission). Range: SGM. Operating beamline. General user allocation: 15%. Local contact: Steven Hulbert, 631-344-7570, hulbert1@bnl.gov. Spokesperson: Steven Hulbert, 631-344-7570, hulbert1@bnl.gov. Beam phone: 5913.

Beamline U13UB

Affiliations: Boston University, Brandeis University, Brookhaven National Laboratory/Physics, Brookhaven National Laboratory/NSLS. Research/Technique: UV/VUV spectroscopy, high resolution, angle resolved photoemission of solid surfaces, pump-probe GU-'98. Range: 5-30 EV. Operating beamline. General user allocation: 25%. Local contact: Steven Hulbert, 631-344-7570, hulbert1@bnl.gov. Spokesperson: Eric Jensen, 781-736-2865, jensen@bnl.gov. Beam phone: 5513.

Beamline U13UC

Affiliations: Lucent Technologies, Inc. Research/Technique: Interferometry. Range: WB. Operating beamline. General user allocation: 25%. Local contact: William Lehnert, 631-344-3635, lehnert@bnl.gov. Spokesperson: Obert Wood, 908-582-4457, orw@bell-labs.com. Beam phone: 5513.

Beamline U14A

Affiliations: Brookhaven National Laboratory/NSLS, Rutgers University. Research/Technique: VUV/soft x-ray spectrocopy auger photo electron co-incidence spectroscopy (APECS). Range: 15-300 EV. Operating beamline. General user allocation: 50%. Local contact: Steven Hulbert, 631-344-7570, hulbert1@bnl.gov. Spokesperson: Steven Hulbert, 631-344-7570, hulbert1@bnl.gov. Beam phone: 5514.

Beamline U14B

Affiliations: Brookhaven National Laboratory/NSLS. Research/Technique: VUV Ring beam position monitoring. Diagnostic beamline. Local contact: Jerry Hastings, 631-344-3930, hastings@bnlls1.nsls.bnl.gov. Spokesperson: Jerry Hastings, 631-344-3930, hastings@bnlls1.nsls.bnl.gov. Beam phone: 5514.

Beamline U15

Affiliations: Brookhaven National Laboratory/NSLS, SUNY @ Buffalo, SUNY @ Stony Brook. Research/ Technique: Soft x-ray spectroscopy (solids and gases). Range: 300-800 EV. Operating beamline. General user allocation: 25%. Local contact: Alex Wen, 631-632-7918, atwen@bnl.gov. Spokesperson: Steven Hulbert, 631-344-7570, hulbert1@bnl.gov. Beam phone: 5515.

Beamline U16B

Affiliations: Brookhaven National Laboratory/NSLS, Rutgers University. Research/Technique: Core level photoemission, soft x-ray photoabsorption spectr., auger photoelect coincidence spectr-APECS. Operating beamline. General user allocation: 50%. Local contact: Steven Hulbert, 631-344-7570, hulbert1@bnl.gov. Spokesperson: Robert Bartynski, 732-445-4839, bart@physics.rutgers.edu. Beam phone: 5516.

Scientists Laszlo Mihaly (SUNY/SB), Lisa Miller, Gwyn Williams and Larry Carr (BNL/NSLS) perform experiments at infrared beamlines U12IR, U10A and U10B.

X-Ray Ring Report

Jeffrey Rothman
X-Ray Ring Manager

This year the X-Ray Ring began 2.8GeV low emittance operations, improving beam brightness substantially. Users on brightness limited beamlines have seen the improvements shown in Table 1 and Figure 1. For typical experiments using 10KeV photons, the brightness has increased by a factor of 3 on the bending magnets and a factor of 4.85 on the X21 and X25 wigglers. X17 is up by a factor of 1.62. The Undulator brightness has gone up even further with X1 improving by a factor of 8.1. The most dramatic increase has been on the IVUN (In Vacuum Undulator) with peak improvements of 45.5 at 5.5KeV and 600 at 16.5KeV on the 1st and 3rd harmonics respectively.

Operating at low emittance and high energy pushes some of the trim dipole magnets close to their maximum current. This limits our ability to perform horizontal orbit corrections for users. The light Source is now working on improved trim strength reduction algorithms to mitigate the problem in the short term. Upgraded trim magnets will be installed to permanently solve the problem. The mechanical group has wound supplementary coils that will be added to a prototype trim magnet. Prior to installation in the ring, the magnet will be carefully tested to determine its thermal properties and the affect of additional inductance on the digital feedback system. The trims will be upgraded one at a time with the reference orbit being re-established before the additional of another upgraded trim.

Running at 2.8GeV with low emittance required upgrading the sextupole power supplies. The new defocusing sextupole supply arrived at the NSLS after a functional inspection at the manufacturers facility. The operational location was prepared, and it was put in place immediately on arrival. The mechanical group then completed the work necessary to connect the magnet coils to the supply. The old defocusing supply was then connected to the focusing sextupole magnet, and the new higher power supply was connected to the defocusing sextupole magnet. This was necessary since we require more current for defocusing than for focusing. Other work included improved read-backs for XQD and the installation of Programmable logic controllers (PLCs) to improve diagnostics, interlocking, and control of power supplies.

Work continued on the digital feedback system. The code was successfully ported from the old CPU to the new Power PC CPU. During studies this prototype system ran at a 550Hz update rate and substantially reduced beam motion in the X-ray ring due to booster operations. Once the code had been ported, Hardware for the operational system was tested in the UV ring. This included new cabling; differential receiver boards to reduce noise pick-up, and fast parallel conversion ADC boards to eliminate timing skew. The new system will use all PUEs and all trims to stabilize the orbit rather than the subset that is used in the current analog system. The operational system will update at a 1kHz rate. The bandwidth of the system will only be limited by the frequency response of the trim magnets. Digital feedback in the UV ring and has been running successfully

Table 1. Improvement in Beam Brightness, 1997 vs. Today

ENERGY (KeV)	X-ray Bend	X21, X25	X1	X17	IVUN
1	2.2	3.5	8.1	1.52	-
5	2.5	4.05	-	1.56	-
5.5	-	-	-	-	45.5 (1st Harmonic)
10	3.0	4.85	-	1.62	-
15	3.6	5.9	-	1.69	-
16.5	-	-	-	-	600 (3rd Harmonic)
20	4.4	7.1	-	1.77	-
25	5.3	8.5	-	1.85	-

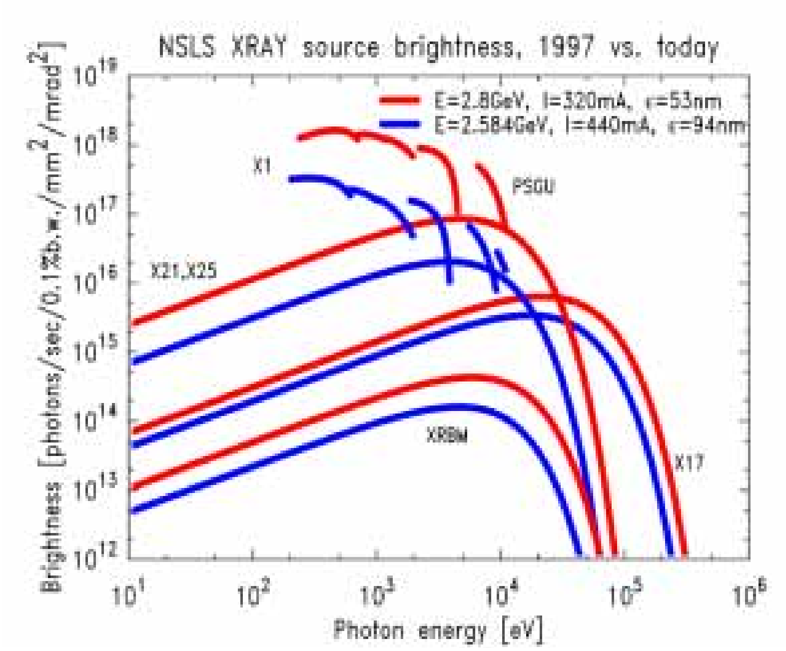


Figure 1. NSLS X-ray Brightness 1997 to 2000

since August, significantly reducing 60Hz beam motion. Studies in the X-ray ring with the new hardware began before the December shutdown. The system ran successfully in one plane with performance comparable to the analog system. When fully implemented, digital feedback should reduce both long-term drift and high frequency beam motion. Initial studies have been limited to one plane, since the wiring for both planes was not completed until the end of December.

Work has been done to characterize vacuum chamber motion as a function of beam current using LVDTs and portable test stands. At high current the heat load on the vacuum chamber causes the chamber to move horizontally. While the amount of motion varies as a function of location, the motion is reproducible from fill to fill. Once the motion is characterized thermistors will be installed on the beam pipe and the data will be used by the digital feedback to compensate for this horizontal motion. Other diagnostics projects include upgrading the ring beam position monitors and expanding the number of active interlock channels in preparation for new IVUNs. Beam loss monitors are also being installed downstream of the dipole magnets inside the X-Ray tunnel. These monitors will allow optimization of injection and reduce fill times.

Unscheduled downtime prompted modifications to the output transmitters in the RF system. The tuning plate assembly, designed by the vendor, provided poor RF contact, causing the transmitter to fail. The RF group increased the tuning plate thickness to ¼", improved the sliding contacts, and added cooling channels. These upgrades allow the transmitters to operate at higher power with less heating, increasing output power from 125kW to 150kW. One of the difficulties associated with adjusting these transmitters is that the tuning of the output stage is temperature dependant and can induce beam instabilities if the heating is excessive. Reducing the operating temperature simplifies maintenance and improves reliability.

Installation of the new X-17 wiggler had been scheduled for the December 1999 shutdown, but was postponed due to a problem discovered during acceptance testing. The final stage of testing called for the magnet to be powered in all three operating modes, then performing integrated magnetic measurements during ramping. At this time the new Danfysik power supplies and the computer control interface were tested. After integrating the power supplies with the control system, the wiggler failed with magnets powered to about 90% of full field. A high internal resistance was measured on the main power lead. The wiggler was sent back to Oxford Instruments Ltd. for repairs. A corporate restructuring delayed the job for a year. Work has resumed and the power lead has been redesigned. The mechanical group has established stringent QA standards for vibration and shock to insure the wiggler will operate properly when it arrives. Return of the wiggler is tentatively scheduled for June 2001. It will then be subjected to extensive offline tests prior to installation. Acceptance tests will be performed to test the control system, establish magnet power ramping rates and to quantify integrated magnetic field errors during power up and ramping. The installation date has not yet been set.

Installation of the X-29 vacuum exit chamber has been delayed due to the long lead-time associated with the 2219 aluminum alloy used in fabrication. Given the tight schedule, we were not able to make up the time and installation of the X-29 vacuum exit chamber has been postponed until the 2001 winter shutdown. This chamber is identical to the ones planned for installation at X-9 and X-13, incorporating exit ports at 0°, 3.5°, and 10°. Installation of the new IVUNs can begin after these chambers are installed.

The stainless steel fast valve blades are being replaced with molybdenum blades due to the higher current and energy in the X-ray ring. The beam is now intense enough to melt through the stainless steel blades in a short period of time. A new water-cooled mask has been installed at X-6 in preparation for the new N.I.H. beamline. The experimental water system is being upgraded with new high flow water spigots, and all polyflow tubing is being replaced with copper pipe to improve reliability and reduce maintenance. The air solenoids are being moved outside of the ring so repairs can be made without breaking ring security. Control and monitoring of the air system is being upgraded from pneumatic to digital units. An interlock is also being added to the air system to reduce moisture when the system switches over to site air.

The breakdown of X-Ray Ring usage is shown in Figure 2. Operations occupied 57.79% of the machine usage in fiscal year 2000. This is a 2.38% increase over 1999. Unscheduled downtime dropped more than 50% from 4.23% to 1.92%. The total integrated current shown in Figure 3 represents an improvement of 87 Amp-Hours over the previous year.

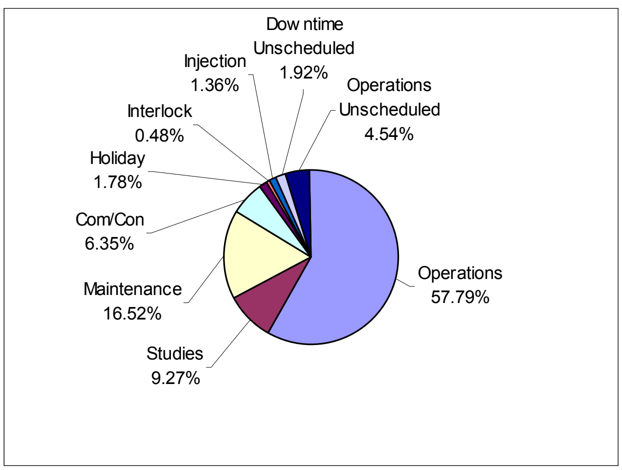


Figure 2: The breakdown of X-Ray Ring usage based on total time (not scheduled time)

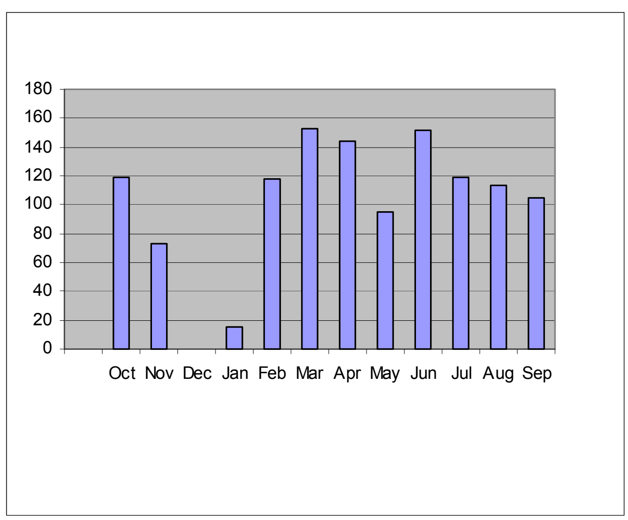


Figure 3: The total integrated current for the X-Ray Ring accumulated each month

X-Ray Storage Ring Parameters as of September 1, 2000

Normal Operating Energies	2.800 GeV
Maximum Operating Current	275mA
Lifetime	14 hours
Circumference	170.1 meters
Number of Beam Ports on Dipoles	30
Number of Insertion Devices	5
Maximum Length of Insertion Devices	< 4.50 meters
$\lambda_c(E_c)$ at 1.36 T	1.75 Å (7.1 keV)
$\lambda_c(E_c)$ at 5.0 T (W)	0.56 Å (22.2 keV)/0.48 Å (26.1 keV)
B(ρ)	1.36 Tesla (6.875 meters)
Electron Orbital Period	567.2 nanoseconds
Damping Times	$\tau_x = \tau_y$ =6 msec; τ_ε = 3 msec/$\tau_x = \tau_y$ =5 msec; τ_ε =2 msec
Touschek (0.25A)	$\geq$ 22 hrs (v_{RF} = 804 kV)/ 57 hrs. (1120 kV)
Lattice Structure (Chasman-Green)	Separated Function, Quad Triplets
Number of Superperiods	8
Magnet Complement	16 Bending (2.7 meters each) 40 Quadrupole (0.45 meters each) 16 Quadrupole (0.80 meters each)
32 Sextupole	(0.20 meters each)
Nominal Tunes (ν_x,ν_y)	3.8, 5.7
Momentum Compaction	0.0049
RF Frequency	52.88 MHz
Radiated Power for Bending Magnets	198 kW (0.25A)
RF Peak Voltage	1120 kV
Design RF Power	450 kW
(Synchrotron Tune) ν_s	0.003
Natural Energy Spread (σ_e/E)	1.01 x 10^{-3}
Natural Bunch Length (2σ)	10.5 cm
Number of RF Buckets	30
Typical Bunch Mode	30
Horizontal Damped Emittance (ε_x)	4.6 x 10^{-8} meter-radian
Vertical Damped Emittance (ε_y)	7.8 x 10^{-11} meter-radian
Power per Horizontal Milliradian (0.25A)	32

Arc Source Parameters

Betatron Function (β_x, β_y)	1.0 to 3.8 m, 7.9 to 26.5 m
Dispersion Function (η_x,η_x)	0.47 to -0.11, -0.39 to 0.22
$\alpha_{x,y}$ = $-\beta'_{x,y}/2$	-0.49 to 1.62, -3.4 to 4.5
$\gamma_{x,y} = (1 + \alpha_{x,y})/\beta_{x,y}$	0.952 to 0.962 m^{-1}, 0.81 to 0.52 m^{-1}
Source Size (σ_x,σ_y)	371 to 612 μm, 27 to 53 μm
Source Divergence (σ_x,σ_y)	476 to 324 μrad, 9 to 7 μrad

Insertion Device Parameters

Betatron Function (β_x, β_y)	1.60 m, 0.35 m
Source Divergence (σ_x, σ_y)	260 μrad, 35 μrad

X-Ray Ring Upgrades

Steven N. Ehrlich

Beamline Technical Liaison

Beamlines X1A and X1B

On the inboard branch of X1A, an ultra-high vacuum chamber for order sorting and Nomarski interference contrast mirror optics was installed. The new room temperature microscope on the inboard branch has become operational and is beginning to deliver scientific results. The outboard branch microscope is scheduled to be replaced by the new design in December 2000. At X1B, the Sawatzky endstation was installed in the position immediately downstream of the exit slit, in June 2000.

Beamlines X3A1 and X3A2

Beamline X3A1 upgraded its SMART1000 detector to the more sensitive and larger surface-area SMART6000 detector, which is based on a 60×60 mm Lockheed-Martin chip. The increase in sensitivity, due to reduced optical taper, allows the study of much smaller crystals, of importance for many of the PRT research programs. In particular, for the time-resolved studies in which a laser beam focused on a 50×50 μm area and uniform illumination is of prime importance, use of small crystals is imperative. The larger area of the detector phosphor (90×90 mm compared with 60×60 mm for the SMART1000) allows collection of complete data sets, including very high-order reflections, in fewer settings of the detector angle, thus improving speed of data collection and accuracy. At X3A2, a specially designed ionization chamber was attached to the exit pinhole so that the beam intensity before the sample could be measured precisely. A data acquisition system was set up for monitoring the beam intensity and multi-channel beam intensity. A dedicated CCD video camera and a hair cross generator were installed for the alignment of samples and the scattering chamber system. An optical rail and positioning system was constructed for the SAXS/WAXD scattering chamber. The chamber position can now be moved freely for different experiments without loss of alignment. This rail/positioning system greatly reduces alignment time, especially for the SAXS studies.

Beamline X4A

Over the past year and a half, X4A has been upgraded in both hardware and software. In spring 1999, implementation of a new Windows driven beamline control system was begun. This program is written in Microsoft Visual C++ and is currently running in Windows 95. In addition to the new motion control program, old individual motor controllers were replaced with Oregon Microsystems controllers. At the same time a new ADSC Q4 CCD detector was installed. The final major upgrade of the beamline was the acquisition and installation of a new sagittal focusing second crystal. The system is based on the design by Andreas Freund's group at the ESRF and manufactured by Oxford Instruments. Bench-top commissioning of the new bender assembly was begun in fall 1999. Initial examination of the bending mechanism using P. Takacs long trace profiler revealed that the focuser could not meet the bend radius that was specified. Despite this major restriction, the mechanism was checked at low energy in the monochromator tank at the end of 1999 and in January 2000. A gear reducer was added (by Oxford) to increase the torque of the drive mechanism and software was modified to accommodate the new monochromator second crystal. The monochromator crystal was installed during the spring shutdown and characterized when x-ray operations resumed. During low emittance, 2.58 GeV mode, the new sagittal focuser was able to focus 2 mRads of radiation to a full width half maximum of 0.3 mm, compared to 0.8 mm for the previous bender.

Beamlines X7A and X7B

A new system to cool the X7A monochromator was implemented and improved the resolution significantly (now ~$2x10^{-4}$ $\Delta d/d$). A new Displex (AirProducts), which operates between 20 and 700K, was installed. A new high-temperature furnace (Tmax~ 1500K) is being constructed. At X7B the spindle axis on the Mar345 was repositioned to allow for a wider range of heater and sample assembles to be mounted. New sample holders/heater assemblies were designed and constructed. These devices incorporate sapphire capillaries and gas flow options that have extended the temperature range (T>1500°C) and types of gas/substrate materials that can be investigated. A new, easily mounted closed-cycle refrigerator cryostat has been incorporated into the beamline for use with gas adsorption studies. Software driven temperature ramps/interval studies are now also possible using Labview based drivers.

Beamlines X8A and X9A

At X8A, beamline control software was completed, tested and installed. In addition, a new lift table was put into operation including developing new software and other control for its operation. The X9A beamline entered full commissioning phase October 1, 2000 with all components working.

Beamlines X11A and X11B

X11A installed a new Huber goniometer during the 11/99–1/00 shutdown. A new vacuum stepping motor and a new piezoelectric crystal was installed on the A-line Huber. 10:1 gear reducers were added to the A-line sample stage. New supports for the ion chambers were designed and installed. A new monochromator (same design as beamline X18B) has been constructed for X11B. It is presently being assembled and installed.

Beamlines X12B and X12C

New optics are being prepared for the X12B and X12C beamlines, to be installed during the early winter shut down, starting in November 2000. New channel-cut monochromators of the Siddons design will go in both beamlines. A collimating mirror will be installed to serve both beamlines X12B and X12C to provide optimum bandpass for these channel-cut crystal monochromators. This mirror will have a fixed radius cut into single-crystal silicon, coated with Pd. This will replace the existing toroidal mirror. The bent-cylinder sagittal focusing mirror at X12C will be inverted from its present configuration: The beam will be deflected upwards 6 mrad by the collimating mirror then back to horizontal by the focusing mirror.

Beamline X14A

A new Nanopure Infinity ultrapure water-purification system was added to the X14A beamline onsite equipment to provide users with high resistive, reagent grade water. A high temperature furnace for in situ powder diffraction measurements in capillary mode and a strong magnetic field device are presently being designed. These two additions will greatly enhance the beamline's capability for in situ experiments.

Beamline X15A

A secondary shutter was implemented in the DEI (Diffraction Enhanced Imaging) system at X15A to allow tuning of the analyzer just before imaging. This upgrade resulted in much more reliable positioning of the analyzer on the rocking curve for DEI. Current operations at X15B use beryl monochromator crystals for 0.8 - 1.6 keV experiments. Thermal interlocks to protect monochromator crystals have been upgraded. Beamline radiation shielding was upgraded to allow operation over a wider range of configurations at 2.8 GeV. Modifications to the vacuum system have added the capability to collect spectra on powdered samples at <15 K in the range 2 – 10 KeV.

Beamline X17B1

A column downstream of the X17B1 hutch is being removed in preparation for the construction of two new hutches to accommodate the current PRT members of X17B1. A radiation survey was conducted and X17B1 was certified to operate at 4.2 Tesla field with a 2.8 GeV ring energy.

Beamline X17C

At X17C, new Kirkpatrick-Baez mirrors were installed with new clean-up slits. The mirrors can focus the beam from 0.04 mm x 0.06 mm to 0.012 mm x 0.010 mm. Compared with a 0.01 mm x 0.01 mm collimator without K-B mirrors, the beam intensity increased by at least 5 times. This is very useful for megabar experiments and micron probe experiments.

Beamline X18B

There were a few major upgrades at the X18B beamline. The monochromator now uses a computerized form of Heidenhein optical encoder for energy correction. In the past, when scanning from the high angle (low energy) side, an energy shift was observed between the first and second scan. A large energy backlash correction was needed to overcome this problem. The optical encoder eliminates this and there is also no need for a three-point calibration, because the angle readout from this device is accurate to within 1 - 2 eV over the whole range of energy. The other major change was the computer control of the detector's Keithley current amplifiers. All of the functions of the amplifiers used in the hutch can now be controlled from outside the hutch by using the LabView program. Sealed gas ion chambers from Oxford were used for all of the transmission and fluorescence experiments. A computerized gas manifold was fabricated with an oil free pump to use the mixture of inert gases for a fixed percent of X-ray absorption.

Beamline X19A

This spring, new InSb monochromator crystals were tested at X19A. The standard Si(111) monochromator crystals have a lattice constant too short to study the P K-edge, which can be done with InSb(111) crystals. The performance of the crystals was very good. After the change to Si(111) for higher energy resolution at higher energies, however, the first crystal, which has to take the heat load from the white beam, showed micro-cracks. Experimental data also showed a slow degradation over time. A different design with better cooling is being studied. In fall 2000, Ge(111) crystals were installed and used for one month. Several EXAFS experiments at the P K-edge were performed and the data quality was much better than that from any previous experimental run with the Si(111) crystals. The problems with EXAFS scans might be related to the quality of the crystals. The sample environment has also been improved in collaboration with D. Hesterberg: the distance sample detector is optimized for the signal-to-background-ratio, the sample can be easily changed and the downtime for flushing the sample environment and ion chamber is reduced. Based on this design, a similar set-up has been adapted for the Lytle liquid N_2 cryostat for XAS studies at low photon energies.

Beamline X20

The X20 beamline data-acquisition/analysis computer was upgraded to an IBM Intellistation workstation running the Red Hat Linux 6.1 operating system. A network printer (Lexmark Optra T612n (capable of Postscript 3)), accessible from beamlines X20A, X20B, X20C and local staff offices, was also installed. Beamline data acquisition software, spec, was upgraded to version 4.05.06. Beamline cooling water system flow capacity was increased to 10 gal/min. Several Proteus water flow units were replaced and the flow rate to the first Be window was recalibrated.

Beamlines X22B and X22C

X22B has increased its versatility in x-ray detection by acquiring a new linear detector with twice the vertical acceptance of the old one, new Soller slits with two adjustable resolution settings and an improved beam attenuator unit. A new computer controlled chiller unit was also acquired to be used with the Langmuir trough and other liquid samples. At X22C, the re-worked Pt-coated, Si mirror was installed and aligned in January 2000. Fabrication of an out-of-plane detector mechanism for surface studies was completed. Preliminary work to increase cooling efficiency of the monochromator was begun. This will be completed next year.

Beamline X23A2

At X23A2, the beamline computer system has been upgraded to a Mac G4 running System 9.

Beamline X24A

At X24A, the Windows beamline control software has been expanded to include control for an ultra-high vacuum chamber. This includes motion of the chamber with respect to the beam and goniometer motion for a sample inside the chamber. The CAMAC control of the beamline and the experimental chamber has been consolidated so that the entire experiment is controlled from a single CAMAC crate. The LINUX beamline control software has been improved to allow feedback on the beam position during long data runs. This requires active control of the beam at the experiment position involving adjustment of the second mirror angle. New settings of the first mirror, closer to the critical angle, have resulted in improvements of net flux and focal spot size at low energies (<3 keV). This is the result of reduced monochromator first crystal heating which compensates for the reduced reflectivity of the first mirror. Additional benefits are longer first crystal life and beam position stability over longer periods of time. Software has been developed to coordinate control of the beamline PC and the PC which controls the hemispherical analyzer electron spectrometer in the Surface Analysis Ultra-high Vacuum Chamber. This allows uniform x-ray photoemission spectra to be obtained as the monochromator is scanned in energy.

Beamline X24C

At X24C, a new 150 g/mm grating was installed in the monochromator diffraction element carousel to increase flux in the 10 to 20 eV range. The beamline monochromator and experimental control computer was upgraded to a modern Pentium PC. A Mac was also added for Internet connection. Silicon photodiode detectors from IRD Inc. were installed in the reflectometer, and new Luxel filters were added to the differential pumping fixture of the calibration chamber.

Beamline X25

At X25, funding was obtained from a variety of sources for a new CCD detector and diffractometer for the macromolecular crystallography program.

Beamline X26A

At X26A, the existing Kirkpatrick-Baez microfocusing system was upgraded to a new system, replacing the bulky translational and rotational motors with smaller Newport motors employing cam-action. This has resulted in a greatly reduced footprint on our experimental table. The control unit was also upgraded to one designed by Peter Eng that integrates with the existing E500 controllers, replacing the larger and more costly Kinetic Systems device. This has resulted in noticeable improvements in microbeam focusing. This year a new Canberra SiLi detector was purchased to replace the aging UCS detectors. The new detector, combined with newer, computer controlled electronics, has yielded improved peak resolution and increases in detector throughput. A new computer control system was installed, replacing the aging VAX workstations. This new system is PC-based, running NT4, and integrates with the existing CAMAC electronics through a VME crate running EPICS. The drivers and hardware integration, similar to software being used by the CARS beamlines at the APS, were developed by Mark Rivers and brings commonality between the CARS operations at APS and the NSLS. It also provides a convenient upgrade path for beamlines, such as X26A, that have a pre-existing investment in CAMAC based electronics. The new EPICS based software provides a new level of flexibility on controlling motors and detectors that was not possible in the past. The usability and quality of microdiffraction analyses at X26A was improved by utilizing the Brucker *SMART* CCD system. With significant improvements in reducing low angle scattering off of the K-B mirrors, addition of motor controlled shutters, and modifications to sample stage design, some very exciting results have been generated on a number of different materials that emphasize the feasibility of combined microbeam XRD-XRF-XANES at X26A

Beamline X26C

X26C purchased a second Octane computer to provide for faster detector image correction, as well as to provide additional computational capacity for data reduction. All vacuum pump controllers and vacuum gauges were replaced with current technology devices resulting in a reliable and auto-restarting vacuum control system. The monochromator cooling system was replaced with a new one that does not require frequent service and operator attention. A new beamline interlock system was built and deployed to provide interlock and diagnostic capabilities for all critical beamline components. New Oxford fluorescence counters (YAP) as well as new ion chamber electronics were purchased and deployed to provide a state-of-the-art compact and reliable method of tracking fluorescent and normal beam intensities. Numerous improvements to the general hutch infrastructure were completed to achieve a rapid changeover capacity when switching diffractometers from the standard crystallography setup to that used for three-beam diffraction experiments. A series of additions and improvements to the various video systems–both stationary and Web-based - were carried out to obtain an excellent teaching facility where students may readily observe the work of experienced investigators.

Beamline X27C

Two beamline upgrades were carried out at X27C in FY 2000. These upgrades included the replacement of the double multilayers (Si/W) in the monochromator. This upgrade was completed in January 2000. The current flux level is about $9x10^{11}$ photon/s at 1.3 Å, which is almost the same as before. The energy resolution ($\Delta E/E$) is 1.1%, which is suitable for polymer study. The pinhole collimation system has also been reconditioned in August 2000. With the first pinhole of 0.1 mm diameter used, the current *d*-space resolution is about 100 nm. The MAR CCD X-ray detector was delivered to X27C in August 2000. Testing of this detector has been completed and with the minimum time resolution of this detector being about 2 s, many new experiments can be carried out.

X-Ray Beamline Guide

Beamline X1A

Affiliations: Argonne National Laboratory, Brookhaven National Laboratory/NSLS, Lawrence Berkeley National Laboratory, North Carolina State University, SUNY @ Stony Brook. Research/Technique: Soft x-ray imaging. Range: 0.25-1 KEV. Operating beamline. General user allocation: 25%. Local contact: Sue Wirick, 631-344-5601, swirick@bnl.gov. Spokesperson: Chris Jacobsen, 631-632-8093, chris.jacobsen@sunysb.edu. Beam phone: 5601.

Beamline X1B

Affiliations: Boston University, Brookhaven National Laboratory/Physics, Forschungszentrum Juelich (KFA), Fritz-Haber-Institut. Research/Technique: Soft x-ray spectroscopy. Range: 0.2-0.9KEV. Operating beamline. General user allocation: 25%. Local contact: Steven Hulbert, 631-344-7570, hulbert1@bnl.gov. Spokesperson: Peter Johnson, 631-344-3705, pdj@bnl.gov. Beam phone: 5701.

Beamline X2B

Affiliations: ExxonMobil Research and Engineering Co. Research/Technique: X-ray microtomography. Range: 6.5-30, WB. Operating beamline. Local contact: Steve Bennett, 631-344-4719, sbennett@bnl.gov. Spokesperson: John Dunsmuir, 908-730-2548, jhdunsm@bnl.gov. Beam phone: 5602.

Beamline X3A1

Affiliations: Alfred University, Amoco Corporation, SUNY @ Buffalo, SUNY @ Stony Brook. Research/Technique: Short wavelength crystallography, diffration and scattering. Range: 31 KEV. Operating beamline. General user allocation: 25%. Local contact: Lynn Ribaud, 716-645-6800,x2218, ribaud@bnl.gov. Spokesperson: Philip Coppens, 716-645-6800, E2217, coppens@acsu.buffalo.edu. Beam phone: 5603.

Beamline X3A2

Affiliations: Alfred University, Amoco Corporation, SUNY @ Buffalo, SUNY @ Stony Brook. Research/Technique: Diffractometry, x-ray spectroscopy, scattering, crystallography, small angle scattering. Range: 3-31 KEV. Operating beamline. General user allocation: 25%. Local contact: Lynn Ribaud, 716-645-6800,x2218, ribaud@bnl.gov. Spokesperson: Philip Coppens, 716-645-6800, E2217, coppens@acsu.buffalo.edu. Beam phone: 5603.

Beamline X3B1

Affiliations: Alfred University, Amoco Corporation, SUNY @ Buffalo, SUNY @ Stony Brook. Research/Technique: XX-ray spectroscopy, powder diffraction. Range: 4-40 KEV. Operating beamline. General user allocation: 25%. Local contact: Peter Stephens, 631-632-8156, Peter.Stephens@sunysb.edu. Spokesperson: Philip Coppens, 716-645-6800, E2217, coppens@acsu.buffalo.edu. Beam phone: 5603.

Beamline X3B2

Affiliations: Alfred University, Amoco Corporation, SUNY @ Buffalo, SUNY @ Stony Brook. Research/Technique: Surface science. Range: 4-20 KEV. Operating beamline. General user allocation: 25%. Local contact: Peter Stephens, 631-632-8156, Peter.Stephens@sunysb.edu. Spokesperson: Philip Coppens, 716-645-6800, E2217, coppens@acsu.buffalo.edu. Beam phone: 5603.

Beamline X4A

Affiliations: Howard Hughes Medical Institute. Research/Technique: Macromolecular crystallography, multiwavelength anom. diff. analysis of crystalline biological macromolecules. Range: 3-20 KEV. Operating beamline. Local contact: Craig Ogata, 631-344-7435, ogata@bnl.gov. Spokesperson: Wayne Hendrickson, 212-305-3456, wayne@convex.hhmi.columbia.edu. Beam phone: 5604.

Beamline X4C

Affiliations: Howard Hughes Medical Institute. Research/Technique: Macromolecular crystallography, diffraction measurements from biology molecules. Range: 3-20 KEV. Operating beamline. Local contact: Craig Ogata, 631-344-7435, ogata@bnl.gov. Spokesperson: Wayne Hendrickson, 212-305-3456, wayne@convex.hhmi.columbia.edu. Beam phone: 5585.

Beamline X5A

Affiliations: Brookhaven National Laboratory/Physics, Forschungszentrum Juelich (KFA), Frascati National Laboratory, Norfolk State University, Ohio University, Osaka University, SUNY @ Stony Brook, Syracuse University, University of Paris, University of Rome II, University of South Carolina, University of Virginia, Virginia Polytechnic Inst. & State University. Research/Technique: Laser Electron Gamma Source (LEGS), medium energy nuclear physics. Range: 140-470MEV. Operating beamline. Local contact: Craig Thorn, 631-344-7798, thorn1@bnl.gov. Spokesperson: Andrew Sandorfi, 631-344-7951, sandorfi@bnl.gov. Beam phone: 5605.

Beamline X6A

Affiliations: Brookhaven National Laboratory/NSLS. Research/Technique: Synchrotron Rad. Inst. Dev.. Diagnostic beamline. Local contact: Peter Siddons, 631-344-2738, siddons@bnl.gov. Spokesperson: Peter Siddons, 631-344-2738, siddons@bnl.gov. Beam phone: 5706.

Beamline X7A

Affiliations: Air Products & Chemicals Inc., Brookhaven National Laboratory/Physics, Carnegie Institute of Washington, Chevron Research & Technology Company, Mobil Technology Company, National Institute of Standards & Technology, SUNY @ Stony Brook, University of California @ Santa Barbara, University of Pennsylvania, UOP. Research/Technique: High resolution structural studies through powder diffraction. Range: 5-45 KEV. Operating beamline. Local contact: Thomas Vogt, 631-344-3731, tvogt@bnl.gov. Spokesperson: Thomas Vogt, 631-344-3731, tvogt@bnl.gov. Beam phone: 5607.

Beamline X7B

Affiliations: Brookhaven National Laboratory/Chemistry, Swedish Natural Science Research Council. Research/Technique: Crystallography, wide angle scattering. Range: 5-21 KEV. Operating beamline. Local contact: Jonathan Hanson, 631-344-4378, hanson1@bnl.gov. Spokesperson: John Larese, 631-344-4349, jzl@bnl.gov. Beam phone: 5707.

Beamline X8A

Affiliations: Bechtel Nevada, Los Alamos National Laboratory, Pacific Northwest National Laboratory, Sandia National Laboratory, Smithsonian Astrophysical Observatory. Research/Technique: Calibration of mirrors & detector systems, material optical constants, spectrometric properties. Range: .26-5.9KEV. Operating beamline. Local contact: Michael Sagurton, 631-344-5708, sagurton@bnl.gov. Spokesperson: Roger Bartlett, 505-667-5923, rbartlett@lanl.gov. Beam phone: 5708.

Beamline X8C

Affiliations: Brookhaven National Laboratory/Biology, Hoffmann-La Roche, Los Alamos National Laboratory, National Research Council of Canada, University of California @ Los Angeles. Research/Technique: Diffraction from biological macromolecules and detector calibrations AXAF. Range: 5-20 KEV. Operating beamline. General user allocation: 25%. Local contact: Leonid Flaks, 631-344-2682, flaks@bnl.gov. Spokesperson: Joel Berendzen, 631-344-6257, joelb@lanl.gov. Beam phone: 5608.

Beamline X9A

Affiliations: Albert Einstein College of Medicine, Rockefeller University, Sloan-Kettering Institute for Cancer Research. Research/Technique: Macromolecular protein crystallography. Range: WB. Operating beamline. General user allocation: 25%. Local contact: Kanagalaghatta Rajashankar, 631-344-7057, raja@bnl.gov. Spokesperson: Mark Chance, 718-430-4136/2894, mrc@aecom.yu.edu. Beam phone: 5787.

Beamline X9B

Affiliations: Albert Einstein College of Medicine, National Institutes of Health. Research/Technique: Small angle scattering, EXAFS, multiple anomalous diffraction (MAD), protein x-ray diffraction. Range: 3-18.8 KEV. Operating beamline. General user allocation: 25%. Local contact: Zbigniew Dauter, 631-344-7367, dauter@bnl.gov. Spokesperson: Mark Chance, 718-430-4136/2894, mrc@aecom.yu.edu. Beam phone: 5609.

Beamline X10A

Affiliations: ExxonMobil Research and Engineering Co. Research/Technique: Small angle x-ray, scattering (SAXS). Range: 6-15.2 KEV. Operating beamline. General user allocation: 25%. Local contact: Steve Bennett, 631-344-4719, sbennett@bnl.gov. Spokesperson: Rainer Kolb, 908-730-2970, rkolb@erenj.com. Beam phone: 5610.

Beamline X10B

Affiliations: ExxonMobil Research and Engineering Co. Research/Technique: General purpose scattering: powder and wide angle x-ray diffraction, x-ray reflectivity. Range: 8,12 KEV. Operating beamline. Local contact: Steve Bennett, 631-344-4719, sbennett@bnl.gov. Spokesperson: Rainer Kolb, 908-730-2970, rkolb@erenj.com. Beam phone: 5710.

Beamline X10C

Affiliations: ExxonMobil Research and Engineering Co. Research/Technique: X-ray absorption spectroscopy (XAS). Range: 4 - 24 KEV. Operating beamline. Local contact: Michael Sansone, 631-344-

5759, msanson@bnl.gov. Spokesperson: Paul Stevens, 908-730-2584, pasteve@erenj.com. Beam phone: 3265.

Beamline X11A

Affiliations: Brookhaven National Laboratory/DAS, E.I DuPont de Nemours and Company, Illinois Institute of Technology, Mobil Technology Company, Naval Research Laboratory, Naval Surface Warfare Center, New Jersey Institute of Technology, North Carolina State University, Paul Scherrer Institute, Rice University, University of Connecticut, University of Washington. Research/Technique: EXAFS and chemical systems in nominal energy range. Range: 4.0-40 KEV. Operating beamline. Local contact: Kaumudi Pandya, 631-344-7734, pandya@sun2.bnl.gov. Spokesperson: Dale Sayers, 919-515-4453, dale_sayers@ncsu.edu. Beam phone: 5611.

Beamline X11B

Affiliations: Brookhaven National Laboratory/DAS, E.I DuPont de Nemours and Company, Illinois Institute of Technology, Mobil Technology Company, Naval Research Laboratory, Naval Surface Warfare Center, New Jersey Institute of Technology, North Carolina State University, Paul Scherrer Institute, Rice University, University of Connecticut, University of Washington. Research/Technique: EXAFS and chemical systems in nominal energy range. Range: 4.0-40 KEV. Operating beamline. Local contact: Kaumudi Pandya, 631-344-7734, pandya@sun2.bnl.gov. Spokesperson: Dale Sayers, 919-515-4453, dale_sayers@ncsu.edu. Beam phone: 5611.

Beamline X12A

Affiliations: Brookhaven National Laboratory/NSLS. Research/Technique: Instrument development and x-ray physics. Diagnostic beamline. Local contact: Peter Siddons, 631-344-2738, siddons@bnl.gov. Spokesperson: Peter Siddons, 631-344-2738, siddons@bnl.gov. Beam phone: 2738.

Beamline X12B

Affiliations: Brookhaven National Laboratory/Biology. Research/Technique: Time-resolved and static x-ray diffraction of macromolecular crystallography. Range: 7.6-13 KEV. Operating beamline. General user allocation: 25%. Local contact: Robert Sweet, 631-344-3401, sweet@bnl.gov. Spokesperson: Robert Sweet, 631-344-3401, sweet@bnl.gov. Beam phone: 5712.

Beamline X12C

Affiliations: Brookhaven National Laboratory/Biology. Research/Technique: Macromolecular crystallography, multi-wavelength anomalous dispersion (MAD). Range: 8-13 KEV. Operating beamline. Local contact: Anand Saxena, 631-344-4844, asaxena@bnl.gov. Spokesperson: Robert Sweet, 631-344-3401, sweet@bnl.gov. Beam phone: 5642.

Beamline X13A

Affiliations: Brookhaven National Laboratory/NSLS. Research/Technique: R&D optics development, soft x-ray utilization. Diagnostic beamline. Local contact: Chi-Chang Kao, 631-344-4494, kao@bnl.gov. Spokesperson: Jerry Hastings, 631-344-3930, hastings@bnlls1.nsls.bnl.gov. Beam phone: 5613.

Beamline X13B

Affiliations: Brookhaven National Laboratory/NSLS. Research/Technique: R&D optics development, soft x-ray utilization. Diagnostic beamline. Local contact: Chi-Chang Kao, 631-344-4494, kao@bnl.gov. Spokesperson: Jerry Hastings, 631-344-3930, hastings@bnlls1.nsls.bnl.gov. Beam phone: 5613.

Beamline X14A

Affiliations: PRT Affiliations: Oak Ridge National Laboratory, Sandia National Laboratory, University of Houston, University of Illinois @ Urbana-Champaign, University of Tennessee. Research/Technique: Scattering crystallography spectroscopy phase ID and resid. strain meas, high temp x-ray diffraction. Range: 2.5-40 KEV. Operating beamline. Local contact: Jianming Bai, 631-344-2583, bai@bnl.gov. Spokesperson: Camden Hubbard, 423-574-4472, hubbardcr@ornl.gov. Beam phone: 5614.

Beamline X14B

Affiliations: Brookhaven National Laboratory/NSLS. Research/Technique: Manuf. Research for hard x-ray lithogrphy exposures for precision microfabrication. Range: WHITE. Operating beamline. Local contact: Erik Johnson, 631-344-4603, erik@bnl.gov. Spokesperson: Erik Johnson, 631-344-4603, erik@bnl.gov. Beam phone: 5614.

Beamline X15A

Affiliations: Argonne National Laboratory, Brookhaven National Laboratory/NSLS, Illinois Institute of Technology, North Carolina State University, Northwestern University, University of North Carolina, University of North Carolina. Research/Technique: X-ray standing waves X-ray optics Medical imaging. Range: 3-20KEV,WB. Operating beamline. General user allocation: 25%. Local contact: Zhong Zhong, 631-344-2117, zhong@bnl.gov. Spokesperson: Michael Bedzyk, 847-252-7763, bedzyk@northwestern.edu. Beam phone: 5615.

Beamline X15B

Affiliations: Lucent Technologies, Inc. Research/Technique: X-ray absorption spectroscopy of complex, reactive, very dilute systems. Range: 1.8-1O KEV. Operating beamline. General user allocation: 25%. Local contact: Paul Northrup, 631-344-3565, northrup@bnl.gov. Spokesperson: Paul Citrin, 908-582-5275, phc@bell-labs.com. Beam phone: 3565.

Beamline X16A

Affiliations: Lucent Technologies, Inc., University of Illinois @ Chicago. Research/Technique: Surface diffraction. Range: 4-12 KEV. Operating beamline. General user allocation: 25%. Local contact: William Lehnert, 631-344-3635, lehnert@bnl.gov. Spokesperson: Kenneth Evans-Lutterodt, 908-582-2154, kenne@lucent.com. Beam phone: 5616.

Beamline X16B

Affiliations: Lucent Technologies, Inc. Research/Technique: Rapid access for sample characterization, powder characterization, thin film chareceterization. Range: 7.85 KEV. Operating beamline. Local contact: William Lehnert, 631-344-3635, lehnert@bnl.gov. Spokesperson: Kenneth Evans-Lutterodt, 908-582-2154, kenne@lucent.com. Beam phone: 5716.

Beamline X16C

Affiliations: Lucent Technologies, Inc., University of Illinois @ Chicago. Research/Technique: Novel spectroscopy, diffraction. Range: 3-16 KEV. Operating beamline. General user allocation: 25%. Local contact: William Lehnert, 631-344-3635, lehnert@bnl.gov. Spokesperson: Kenneth Evans-Lutterodt, 908-582-2154, kenne@lucent.com. Beam phone: 5816.

Beamline X17B1

Affiliations: Brookhaven National Laboratory/NSLS, SUNY @ Stony Brook. Research/Technique: X-ray scattering at high pressure and temperature. Range: 20-100, WB. Operating beamline. General user allocation: 75%. Local contact: Zhong Zhong, 631-344-2117, zhong@bnl.gov. Spokesperson: Jerry Hastings, 631-344-3930, hastings@bnlls1.nsls.bnl.gov. Beam phone: 5717.

Beamline X17C

Affiliations: Carnegie Institute of Washington, Lawrence Livermore National Laboratory, Naval Research Laboratory, University of Chicago. Research/Technique: Hi P research, energy dispersive diffraction from microscopic sample volumes. Range: 10-100, WB. Operating beamline. General user allocation: 25%. Local contact: Jingzhu Hu, 202-686-2410, jzhu@bnl.gov. Spokesperson: Ho-kwang Mao, 202-686-4454, hkmao@bnl.gov. Beam phone: 5917.

Beamline X18A

Affiliations: Brookhaven National Laboratory/DAS, Pennsylvania State University, Purdue University, University of Illinois @ Chicago, University of Maryland, University of Missouri. Research/Technique: Diffuse and surface scattering. Range: 4-20 KEV. Operating beamline. Local contact: Yufei Hu, 301-

405-0399, yufeihu@eng.umd.edu. Spokesperson: Paul Sokol, 814-863-5811, pes4@psu.edu. Beam phone: 5618.

Beamline X18B

Affiliations: AlliedSignal, Inc., Brookhaven National Laboratory/NSLS, Chevron Research & Technology Company, Dow Chemical Company, General Electric, PPG Industries, Inc., UOP. Research/Technique: X-ray spectroscopy. Range: 7-40 keV. Operating beamline. General user allocation: 25%. Local contact: Syed Khalid, 631-344-7496, khalid@bnl.gov. Spokesperson: Wolfgang Caliebe, 631-344-4744, caliebe@bnl.gov. Beam phone: 5718.

Beamline X19A

Affiliations: Brookhaven National Laboratory/DAS, Brookhaven National Laboratory/NSLS, Brookhaven National Laboratory/Chemistry Rutgers University, University of California @ Davis, University of Kentucky. Research/Technique: X-ray absorption spectroscopy: EXAFS and XANES. Range: 2 - 8 KEV. Operating beamline. General user allocation: 25%. Local contact: Wolfgang Caliebe, 631-344-4744, caliebe@bnl.gov. Spokesperson: Wolfgang Caliebe, 631-344-4744, caliebe@bnl.gov. Beam phone: 5619.

Beamline X19C

Affiliations: Army Research Laboratory, Dartmouth College, Johns Hopkins University, National Aeronautical and Space Agency, Northrop Grumman ATDC, SUNY @ Stony Brook, University of Chicago, University of Illinois @ Chicago, University of Wisconsin. Research/Technique: Topography liquid surface scattering. Range: 6-17keV,WB. Operating beamline. General user allocation: 25%. Local contact: Aleksey Tikhonov, 631-344-5719, Alexeit@uic.edu. Spokesperson: Mark Schlossman, 312-996-8787, schloss@uic.edu. Beam phone: 5719.

Beamline X20A

Affiliations: IBM Research Division, Massachusetts Institute of Technology. Research/Technique: X-ray scattering and diffraction. Range: 6.3-12 KEV. Operating beamline. Local contact: Jean Jordan-Sweet, 914-945-3322, jlj@bnl.gov. Spokesperson: Robert Birgeneau, 617-253-4937, robertjb@bnl.gov. Beam phone: 5720.

Beamline X20B

Affiliations: IBM Research Division, Massachusetts Institute of Technology. Research/Technique: Scattering at fixed energy. Range: 17.4 KEV. Operating beamline. Local contact: Jean Jordan-Sweet, 914-945-3322, jlj@bnl.gov. Spokesperson: Jean Jordan-Sweet, 914-945-3322, jlj@bnl.gov. Beam phone: 5192.

Beamline X20C

Affiliations: IBM Research Division, Massachusetts Institute of Technology. Research/Technique: X-ray scattering and diffraction with high flux by multilayer monochromator. Range: 4-11 KEV. Operating beamline. Local contact: Jean Jordan-Sweet, 914-945-3322, jlj@bnl.gov. Spokesperson: Jean Jordan-Sweet, 914-945-3322, jlj@bnl.gov. Beam phone: 5720.

Beamline X21

Affiliations: Brookhaven National Laboratory/NSLS. Research/Technique: Inelastic x-ray scattering. Range: 5-10 KEV. Operating beamline. General user allocation: 25%. Local contact: Chi-Chang Kao, 631-344-4494, kao@bnl.gov. Spokesperson: Chi-Chang Kao, 631-344-4494, kao@bnl.gov. Beam phone: 5721.

Beamline X22A

Affiliations: Brookhaven National Laboratory/Physics, Brookhaven National Laboratory/DAS, University of Maryland. Research/Technique: X-ray scattering of thin films, multilayers, catalytic materials, electrochemical interfaces. Range: 10 KEV NOM. Operating beamline. Local contact: John Hill, 631-344-3736, john@solids.phy.bnl.gov. Spokesperson: Doon Gibbs, 631-344-4608, doon@bnl.gov. Beam phone: 5622.

Beamline X22B

Affiliations: Argonne National Laboratory, Brookhaven National Laboratory/Physics, Harvard University. Research/Technique: X-ray scattering and spectroscoppy of liquid surfaces, magnetic stud.under magnetic fields. Range: 5-10 KEV. Operating beamline. Local contact: Elaine DiMasi, 631-344-2211, dimasi@solids.phy.bnl.gov. Spokesperson: Doon Gibbs, 631-344-4608, doon@bnl.gov. Beam phone: 5622.

Beamline X22C

Affiliations: Argonne National Laboratory, Brookhaven National Laboratory/Physics, University of Maryland. Research/Technique: X-ray Scattering studies of magnetism, structure and phase behavior of metal surfaces. Range: 3-12 KEV. Operating beamline. Local contact: John Hill, 631-344-3736, john@solids.phy.bnl.gov. Spokesperson: Doon Gibbs, 631-344-4608, doon@bnl.gov. Beam phone: 5622.

Beamline X23A2

Affiliations: National Institute of Standards & Technology. Research/Technique: EXAFS. Range: 4.7-30 KEV. Operating beamline. General user allocation: 25%. Local contact: Joseph Woicik, 631-344-5236, woicik@bnl.gov. Spokesperson: Joseph Woicik, 631-344-5236, woicik@bnl.gov. Beam phone: 5823.

Beamline X23A3

Affiliations: National Institute of Standards & Technology. Research/Technique: Topography, small-angle scattering. Range: 5-30KEV,WB. Operating beamline. General user allocation: 25%. Local contact: Daniel Fischer, 631-344-5177, dfischer@bnl.gov. Spokesperson: Gabrielle Long, 301-975-5975, gabrielle.long@nist.gov. Beam phone: 5623.

Beamline X23B

Affiliations: Naval Research Laboratory. Research/Technique: X-ray absorption Diffraction Measurements. Range: 3-10.5 keV. Operating beamline. General user allocation: 25%. Local contact: Johnny Kirkland, 631-344-2258, kirkland@bnl.gov. Spokesperson: Vincent Harris, 202-767-6249, harris@anvil.nrl.navy.mil. Beam phone: 5723.

Beamline X24A

Affiliations: Brookhaven National Laboratory/NSLS, City University of New York, National Institute of Standards & Technology, University of Maryland, University of Rhode Island, University of Tennessee. Research/Technique: Atomic, molecular, and optical physics with x-rays. Range: 1 - 5 KEV. Operating beamline. General user allocation: 25%. Local contact: Barry Karlin, 631-344-5624, karlin@bnl.gov. Spokesperson: Terrence Jach, 301-975-2362, terrence.jach@nist.gov. Beam phone: 5624.

Beamline X24C

Affiliations: Naval Research Laboratory. Research/Technique: Photoemission and reflectance spectroscopy. Range: .006-1.8KE. Operating beamline. General user allocation: 25%. Local contact: Jack Rife, 202-767-4654, rife@nrl.navy.mil. Spokesperson: Jack Rife, 202-767-4654, rife@nrl.navy.mil. Beam phone: 5723.

Beamline X25

Affiliations: Brookhaven National Laboratory/NSLS. Research/Technique: High intensity, high brightness photon beam, high Q-resolution elastic scattering. Range: 3-30 KEV. Operating beamline. General user allocation: 75%. Local contact: Lonny Berman, 631-344-5333, berman@bnl.gov. Spokesperson: Lonny Berman, 631-344-5333, berman@bnl.gov. Beam phone: 5625.

Beamline X26A

Affiliations: Brookhaven National Laboratory/Biology, Brookhaven National Laboratory/DAS, Cold Spring Harbor Laboratory, SUNY @ Stony Brook, University of Chicago, University of Georgia. Research/Technique: X-ray Microscopy, structural biology, atomic and molecular physics. Range: 4-20KEV,WB. Operating beamline. Local contact: Antonio Lanzirotti, 631-344-5626, lanzirotti@bnl.gov. Spokesperson: Stephen Sutton, 630-252-0426, sutton@cars.uchicago.edu. Beam phone: 5626.

Beamline X26C

Affiliations: Brookhaven National Laboratory/DAS, Brookhaven National Laboratory/Biology, Cold Spring Harbor Laboratory, SUNY @ Stony Brook, University of Chicago, University of Georgia. Research/Technique: Macromolecular x-ray crystallography using intense monochomatic and focused white beam. Range: 4-30KEV,WB. Operating beamline. General user allocation: 25%. Local contact: Dieter Schneider, 631-344-3423, schneider@bnl.gov. Spokesperson: Dieter Schneider, 631-344-3423, schneider@bnl.gov. Beam phone: 5726.

Beamline X27A

Affiliations: Brookhaven National Laboratory/NSLS. Research/Technique: NSLS R&D only, instrument development and x-ray physics. Diagnostic beamline. Local contact: Peter Siddons, 631-344-2738, siddons@bnl.gov. Spokesperson: Peter Siddons, 631-344-2738, siddons@bnl.gov. Beam phone: 5738.

Beamline X27B

Affiliations: Brookhaven National Laboratory/NSLS. Research/Technique: NSLS R&D only, develop exposure techniques, matls. char., and tool development for microfab.. Diagnostic beamline. Local contact: Erik Johnson, 631-344-4603, erik@bnl.gov. Spokesperson: Erik Johnson, 631-344-4603, erik@bnl.gov. Beam phone: 5627.

Beamline X27C

Affiliations: AlliedSignal, Inc., Brookhaven National Laboratory/Physics, General Electric, Montell Polyolefins USA, National Institute of Standards & Technology, National Institutes of Health, SUNY @ Stony Brook, U.S. Air Force. Research/Technique: Simultaneous small & wide angle x-ray scattering (SWAX) in real time. Operating beamline. Local contact: Feng-ji Yeh, 631-632-7892, fyeh@bnl.gov. Spokesperson: Benjamin Hsiao, 631-632-7793, Benjamin.Hsiao@sunysb.edu. Beam phone: 5627.

Beamline X28A

Affiliations: Brookhaven National Laboratory/NSLS. Research/Technique: Instrument development, photon-based diagnostics and detector development for the X-ray Ring. Diagnostic beamline. Local contact: Erik Johnson, 631-344-4603, erik@bnl.gov. Spokesperson: Steven Ehrlich, 631-344-7862, ehrlich@bnl.gov. Beam phone: 5728.

Beamline X28B

Affiliations: Brookhaven National Laboratory/NSLS. Research/Technique: Photon-based diagnostics and detector development for the X-ray Ring. Diagnostic beamline. Local contact: Erik Johnson, 631-344-4603, erik@bnl.gov. Spokesperson: Steven Ehrlich, 631-344-7862, ehrlich@bnl.gov. Beam phone: 2117.

Beamline X28C

Affiliations: Albert Einstein College of Medicine. Research/Technique: Time-resolved x-ray footprinting. Operating beamline. General user allocation: 25%. Local contact: Narcisse Komas, 631-344-2308, komas@bnl.gov. Spokesperson: Mark Chance, 718-430-4136/2894, mrc@aecom.yu.edu. Beam phone: 2117.

Beamline X30

Affiliations: Brookhaven National Laboratory/NSLS. Research/Technique: Diagnostic Instrument. Diagnostic beamline.

Future Light Sources Based upon Photo-injected Energy Recovery Linacs

Ilan Ben-Zvi on behalf of the NSLS PERL Study Group
Accelerator Test Facility Head

Electron storage rings currently provide the vast majority of the light employed in synchrotron radiation based research. The envelope of straightforward enhancements in storage rings has been exhaustively explored and the limits of their performance are well known. One persistent boundary in these machines is bunch-length; no practical means has been found to allow bunches of less than a few picoseconds duration to be stored. The properties of linear accelerator beams are quite different, and it has been demonstrated that electron bunches down to 100 femtoseconds can be produced.

A key quality factor for a light source is the photon brightness, which is related to the electron beam emittance in the accelerator. For a ring with a Chasman-Green lattice, the horizontal emittance $\varepsilon_x \sim \gamma^2/M^3$, where γ is the electron energy in units of the rest mass and M is the number of superperiods. Hence, the scaling is such that it becomes more difficult to obtain very small emittance at higher energies. In a linac, using a photoinjector [Fraser & Sheffield], the emittance $\varepsilon \sim \varepsilon_n/\gamma$, where the normalized emittance ε_n is independent of energy, and it is believed to be possible to achieve $\varepsilon_n = 1\pi$ mm-mrad. Therefore, Photoinjected linac sources may provide the best approach to achieve emittances of 0.1 nm-rad at 3-6 GeV electron energy with sub-picosecond pulses.

The Energy Recovering Linac (ERL), proposed initially for high-energy physics applications in 1965 [M. Tigner], allows very high average electron currents. Thomas Jefferson National Accelerator Facility has recently demonstrated the efficacy of the principle [Neil *et.al.*]. In the last few years several research groups [Karyan *et.al.,* Douglas, Gruner *et.al.*] have been considering the potential of using linac sources for providing incoherent synchrotron radiation. One reason this is not commonly done is that achieving high average currents, on the order of a few hundred mA, has been commonplace in storage rings but has not yet been achieved in linacs. Recent developments [Neil *et.al.*, Dowell *et.al.*] have made it seem much more likely that average currents of a few hundred mA can be achieved in linacs with energy recovery.

At BNL we have been looking at a few applications of PERL with an average current in the hundreds of mA: A multi GeV high-brightness electron-hadron collider, [I. Ben-Zvi, J. Murphy *et.al.*]; an electron cooler for RHIC; and a light-source, the subject of this report (**Figure 1**).

The Photoinjected Energy Recovery Linac offers crucial advantages for a new user-oriented light source, including high brightness (**Figure 2**) and coherence, and unique temporal structure. These characteristics significantly advance current performance and are well-matched to future applications of synchrotron radiation probing of matter. The PERL provides a new paradigm for synchrotron light sources and the National Synchrotron Light Source is studying the feasibility of a PERL as a future light source for the NSLS user community.

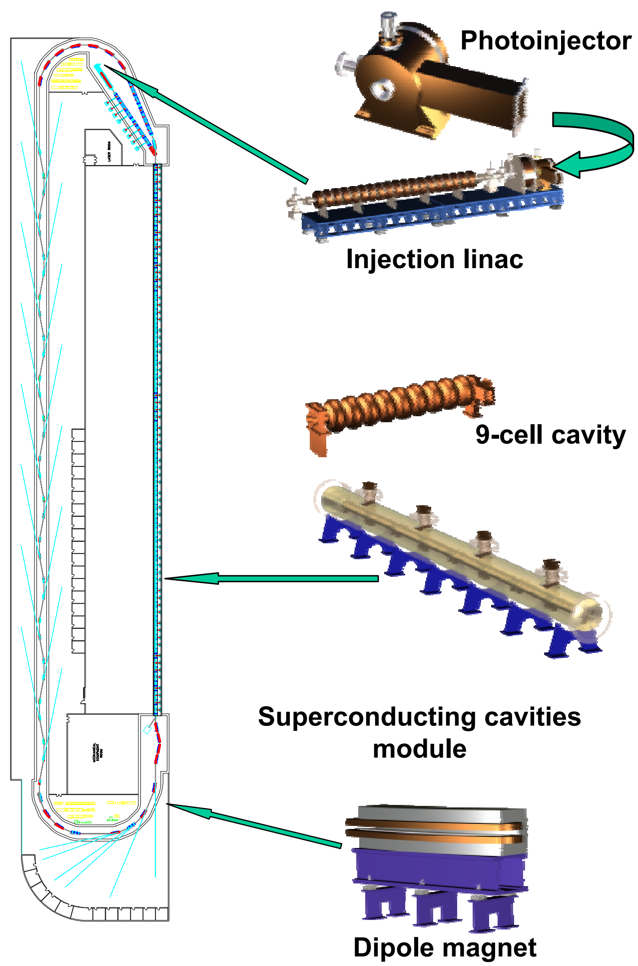


Figure 1. *PERL layout. Light green lines represent synchrotron radiation beam lines.*

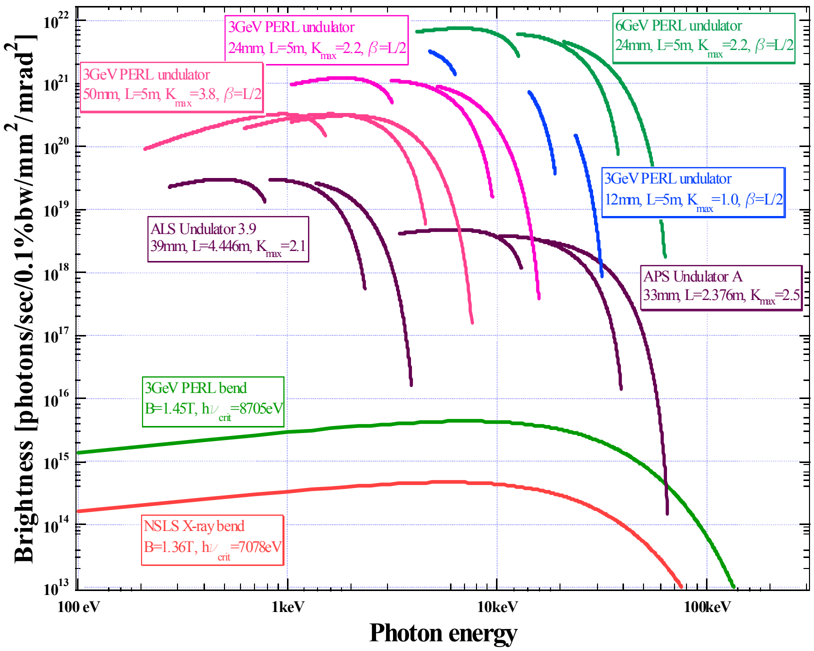


Figure 2*. PERL Insertion Devices and bend source brightness compared to ALS and APS sources as a function of photon energy on a log-log scale. An insertion device of a 6 GeV PERL is presented by the highest brightness curve (green). Insertion Devices of a 3 GeV PERL are presented by the next three highest brightness curves (blue, violet and red). For comparison the ALS and APS sources are given in black. At the bottom, a 3 GeV PERL bend is shown in green and compared to an NSLS bend in red.*

Source parameters which appear to be achievable with a PERL light source are:

- Diffraction-limited source to:
  - 10~20Å in BOTH planes, $\varepsilon_x\varepsilon_y$~ (1-3Å)^2 at 3-GeV.
  - 5~10Å in BOTH planes, $\varepsilon_x\varepsilon_y$~(0.25-0.75Å)^2 at 6-GeV.
- Variable ε_x /ε_y emittance ratio, (at a constant product $\varepsilon_x\varepsilon_y$) allowing either a round beam or an extremely small vertical emittance (with larger horizontal emittance) on demand.
- Sub-picosecond pulses with an eye towards achieving 100 fs.
- Virtual 'top-off' yielding a constant heat load on chambers, optics.
- High long-term stability.
- Electro-optical control of the pulse-format through the laser (spacing, pseudo-random sequences of arbitrary length, variable charge, variable pulse length).

There are many physics and technology issues to be resolved before a PERL is possible, and the NSLS PERL Study Group is pursuing these.

Acknowledgements

I wish to thank the members of the NSLS PERL study group for the enthusiastic work on the subject and our many colleagues in other laboratories who are pursuing research along similar lines for their stimulating interactions.

References

D. Douglas, "Incoherent Thoughts about Coherent Light Sources", JLAB-TN-98-040.

D.H. Dowell *et.al.*, "First Operation of a Photocathode Radio Frequency Gun Injector at High Duty Factor", Appl. Phys. Lett. 63 (15), 2035 (1993).

J. Fraser, R. Sheffield, " High Brightness Photoemitter Injector for Electron Accelerators", Nucl. Instr. & Meth. A250 (1986), pp. 71-76.

S. Gruner, D. Bilderback, M. Tigner, "Synchrotron Radiation Sources for the Future", Cornell University, Internal Report, September 2000.

D.A. Kayran, et. al., "MARS –A Project of the Diffraction Limited Fourth Generation X-ray Source", Proc. 1998 Asian Particle Accelerator Conference.

G.R. Neil *et.al.*, "Sustained Kilowatt Lasing in a Free-Electron Laser with Same-Cell Energy Recovery", Phys. Rev. Lett., 84 (4), 662-665 (2000).

M. Tigner, "A possible apparatus for clashing-beam experiments." Nuovo Cimento **37,** 1228 (1965).

The Deep UltraViolet – Free Electron Laser

Erik D. Johnson

Head of the NSLS Experimental Systems Group, Project Manager for the DUV-FEL

The pieces for the DUV-FEL are slotting into place. During the last year the linac installation was completed and commissioning is underway. The results of the HGHG experiment in the infra-red completed at the ATF were published in Science this summer, providing a solid experimental as well as theoretical basis for the DUV-FEL. Magnetic measurements and shimming of NISUS, the amplifier wiggler for the DUV-FEL, were completed and installation of the diagnostics is underway. Each component of this puzzle has involved the tireless efforts of a combination of members of the NSLS staff, as well as support of other departments, the laboratory management, and collaborators from other institutions off site. Seeing these pieces at last come together is extremely exciting for all of us involved with the project. Read on and perhaps you will begin to share our enthusiasm!

The Source Development Laboratory (SDL) was created by the NSLS as a resource to provide a sound technological foundation for sources and science that will lead to the next generation of synchrotron radiation based research. BNL shares the view with many other laboratories that these machines will be Free Electron Lasers, and that getting to short wavelengths will require single pass configurations. BNL's unique perspective is that these machines must wed the best aspects of solid state lasers with accelerator technology to be useful experimental tools. The source must have the stability and optical quality people have come to expect in laser technology, while operating at wavelengths that are only readily accessible using accelerator based amplifiers. The High Gain Harmonic Generation (HGHG) approach demonstrated in the infra-red by Li-Hua Yu and his collaborators is the central concept for the Deep-Ultra-Violet Free Electron Laser (DUV-FEL), which is the principle activity of the SDL.

In the DUV-FEL, UV light from a solid state laser (Titanium:Sapphire with conventional harmonic generation) is used to illuminate the cathode of an RF photo-injector. This generates an intense electron bunch that is accelerated by an electron linac. The electrons then pass through a short magnetic wiggler where they are coupled with light split off from the laser. The resulting energy modulation is then converted to spatial modulation (micro-bunching) in a dispersive section. A longer wiggler is then used to generate FEL radiation at harmonics of the initial seed laser. This process produces radiation with optical properties and stability that are controlled by the original seed laser (pulse length, bandwidth, coherence). The HGHG experiment at the ATF demonstrated conversion from 10 micron wavelength seed radiation to 5 micron wavelength FEL radiation. In its initial configuration the DUV-FEL will allow operation at wavelengths down to 200 nm at pulse lengths below a picosecond. Planned enhancements can extend this performance to wavelengths the order of 50 nm and pulse lengths as short as 10 femtoseconds.

One way to view the DUV-FEL is essentially as a harmonic generation and amplification system for a solid-state laser. Whatever you can produce in the laser can in principle be carried through to the FEL output. This includes its stability as well as programmed pulse formats that can be used to make the FEL a chirped pulse amplification system, potentially yielding pulses shorter than 10 femtoseconds at wavelengths below 100 nm with energies up to a milli-Joule. These properties should prove valuable to experimental users of the DUV-FEL. The other obvious feature of the facility is that pump-probe multicolor experiments should be readily possible with excellent timing jitter if the alternate colors can be derived from the facility laser. It should be noted that the tuning agility of the FEL depends on the tuning of the seed laser. The bandwidth of the Ti:Sapp is sufficient for small tuning ranges with relative ease, but broadly tunable operation will depend on enhancing its capabilities over the present system.

Most of the equipment has been recovered from other projects and modified or improved to make it suitable for the DUV-FEL. Reconfiguration of the linac for FEL operation has been a major task involving the addition of a photoinjector system and a pulse compression chicane to increase the peak current of the electron beam. Only the skill and energy of the project team working together have made this possible. John Skaritka is the chief engineer for the project, with the linac redesign and commissioning guided by Bill Graves and Richard Heese. XiJie Wang was responsible for the photo-injector while Lou DiMauro and Brian Sheehy lead the laser implementation and optical program development effort. The computer control system development was lead by Kate Feng-Berman and electrical engineering was provided by Jeff Rothman and Jim Rose. Bob Casey and Nick Gmur made navigation of the regulatory and procedural requirements possible. Several students and postdocs have also made the DUV-FEL a major part of their work including Charles Neuman, Juana Rudati, and Timur Shaftan. Finally, none of us would have anything to show were it not for the work of the technical group lead by Boyzie Singh including Jim Anselmini, Jeb Barry, Joe Greco, and Phil

Marino, frequently supplemented by help from other sections of the NSLS.

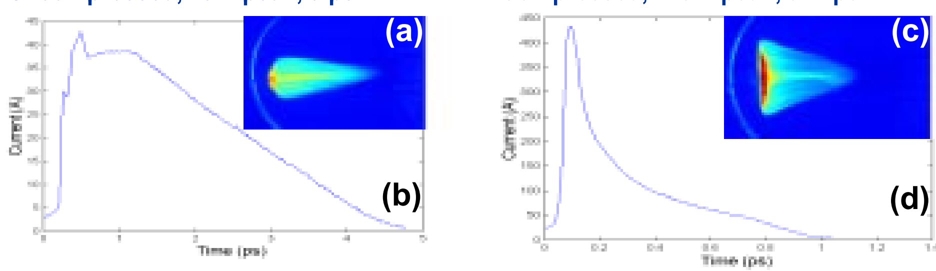
Permission was granted to start commissioning and testing of the linac in April 2000. In a recent electron beam study lead by Bill Graves, compression of more than a factor of 10 was achieved as shown below. In this case the bunch length was measured by introducing a correlated energy chirp on the bunch and dispersing it across a screen with a dipole magnet. Other non-disrupting short bunch diagnostics are under development including several measurements based on the production of coherent infra-red radiation in magnets along the linac. Developing the tools and techniques to reliably produce high quality electron beam day in and day out is one of the core goals of the project.

To convert some of the electron beam energy to light, high precision undulators are required. NISUS, our 10 meter long amplifier wiggler, was measured and shimmed in an effort lead by George Rakowsky. The anticipated trajectory walk-off was reduced from a preshimming value of nearly 30 *millimeters* to a final value of less than 25 *microns* and a final optical phase error of only 4°. When the installation of the vacuum chamber and diagnostics is completed, the linac will be connected to NISUS and FEL experiments will start.

Li-Hua Yu is responsible for the development of the DUV-FEL program. Initially we will run as a Self-Amplfied Spontaneous Emission (SASE) FEL in the visible. No laser seeding is required for this mode of operation, and by turning down the electron energy to run in the visible, readily available high performance diagnostics can be used to tune the machine. As the visible SASE work proceeds preparations will continue to implement HGHG. The energy modulator and dispersive section from the ATF based experiment will be installed at the SDL for the DUV-FEL. Looking further ahead, anticipated energy upgrades of the machine will allow operation below 100nm. When this milestone is achieved, proof-of-principle user experiments are planned that will test the mettle of this exciting new source of light.

SDL Electron Beam Studies:

Uncompressed, 40 A peak, 3 ps FWHM — **Compressed, 425 A peak, 0.2 ps FWHM**



Beam Parameters		Compressor	Linac	Visible	Lattice Studies
Energy	[MeV]	82	200	140	195
Energy Spread	[%]	0.2	0.07	0.1	0.08
Bunch Length	[ps]	2-3	0.2-3	1.0	~4
Charge	[pC]	100	100	400	250
Emittance	[mm-mrad]	4-8	4-8	5	~3 at 80 MeV
Timing Stability	[ps]	0.5-3	0.5-3		

(a) Image of uncompressed beam on YAG:Ce scintillator. (b) Current profile of uncompressed beam showing 3ps bunch length and 40 A peak. (c) Image of compress beam on YAG:Ce scintillator. (d) Profile showing 0.2 ps bunch length 425 A peak current of compressed bunch.

The Accelerator Test Facility

Ilan Ben-Zvi
Accelerator Test Facility Head

The Accelerator Test Facility (ATF), a user's facility dedicated to advanced accelerator R&D. It is the home for research on future light source science. In this report you may read on the way in which research done at the ATF is relevant to future of X-ray light-sources. To provide two examples: 1. The proof-of-principle experiment on High-Gain Harmonic-Generation Free-Electron Lasers was done at the ATF [L.-H. Yu, et.al. Science, **289** (2000) 932]. 2. The ATF provided the idea and the technology for the Photoinjected Energy Recovering Linac (PERL) upgrade, [see article in this report] a machine emerging from the union of two technologies: laser-photocathode RF guns (photoinjectors) and superconducting linear accelerators with beam energy recovery (Energy Recovering Linac).

In the nine years of its service to the Physics of Beams community, the ATF users achieved numerous 'firsts' and technological breakthroughs as well as providing graduate education in physics of beam for many students (15 students from 8 universities graduated since 1992).

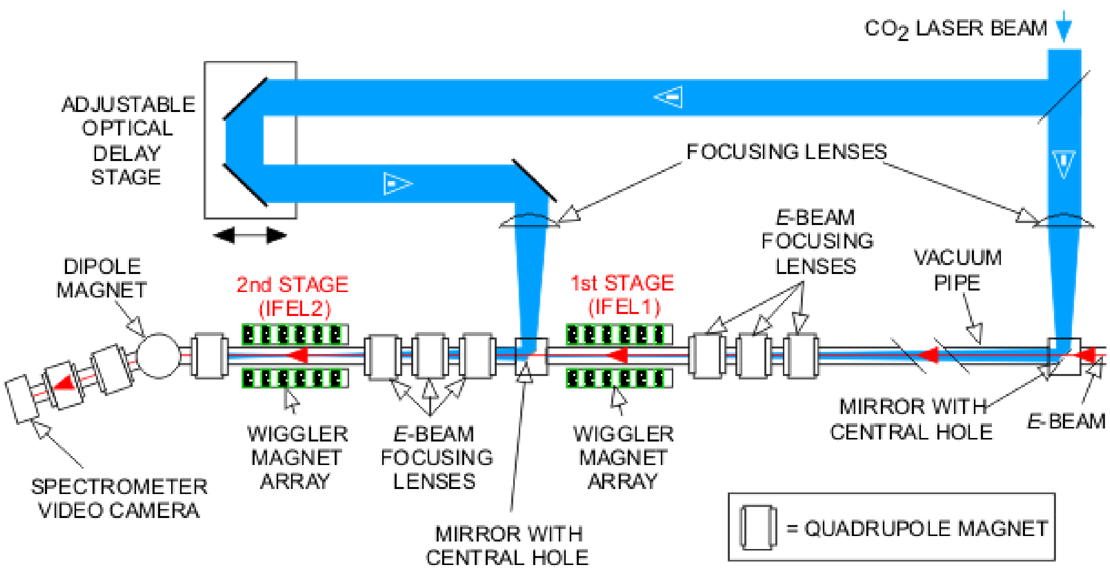
The generation and acceleration of very high brightness electron beams is a key technology for the PERL upgrade, for short wavelength FELs as well as other applications, including linear colliders, Compton backscattering for the production of femtosecond x-rays, laser accelerators and more. A high brightness means that the electron bunch has a high density in 6-D phase space. To achieve high brightness beams, it is necessary to do the following: 1) Master the production of such beams in special electron guns. 2) Develop diagnostics that provide information of the 6-D distribution of electron bunches on sub-picosecond time scales. 3) Control the 6-D distribution of the bunch in various ways. 4) Accelerate the electrons to high energies without diluting the brightness.

The electron beam sources in most national and international laboratories are based on photoinjectors developed at BNL. In particular, recent guns such as the ones at SLAC, UCLA, University of Tokyo, the LEUTL facility at the APS, the SDL at the NSLS and of course at the ATF, are based on R&D carried out by Xijie Wang, the Deputy Head of the ATF.

In the following I will underscore some of the new developments at the ATF.

The ATF has recently upgraded its accommodations for staff & experimenters, including a new ATF Computer Room with expanded printing facilities, remote computer control system access in the Experiment Hall, Control Room reconfiguration and addition of new equipment racks and a spacious experimental area, a dedicated user's testing & assembly area, dedicated helium and nitrogen gas supplies for the Experimental Hall, and more.

The beam lines are also undergoing continuous improvements. For example, recently we successfully sent an electron beam through the Compton cell [see report in the 1999 NSLS Activity Report] through new, miniature permanent-magnet quadrupoles on beamline 1. The purpose of these quadrupoles is to allow us to generate a very small spot size. This is important for many experiments, including the Compton experiment



aimed at producing an even larger flux of picosecond and sub-picosecond hard X-rays. The initial results are encouraging. We did not have time to optimize the tuning but we did observe a 40 microns (sigma) electron beam in the middle of the chamber for 0.5 nC beam. There is reasonable confidence in the further reduction of the beam size by factor 2-4.

The MathCAD interface to our control system was extensively used for everyday operations this year. One example can be a program that automatically collects information about the photo-injector and laser performance every morning. That one page program has proven to be very useful in the operator independent basic parameters recording. A sample of pages generated by the program can be found at http://nslsweb.nsls.bnl.gov/AccTest/R0/Photoinj.html. The data is used to evaluate changes in the laser stability, reasons for quantum efficiency drops, etc.

Other examples are the gun and linac feedback systems, usually used to overcome temporally problems with RF stability. These problems were resolved by fixing the sources of such instabilities (replacing unstable power supplies, fixing bad contact or soldering joint). Since it takes weeks to find intermittent problems, the feedback programs allow us to minimize the effects of such a condition on the experimental program. We often use the linac feedback program now but did not use gun feedback since late October but it is ready to go should we need it.

The ATF terawatt CO2 laser is nearing a milestone test. An intense effort is underway with a near-term goal of bringing the high-pressure booster amplifier on line at sub-terawatt output peak power (~10 J @ 30 ps) in January 2001. This will provide approximately a 300 times increase in comparison with the present ATF laser.

Our next schedule is to use 300 GW laser beam to demonstrate greatly enhanced x-ray yields and nonlinear effects in the Compton scattering experiment (February 2001). Our longer-term goal is to achieve ~10 J @ 1 ps.

Another subject of intense research is the photocathode RF gun, which is so critical for the new generations of light sources (PERL and FEL). ATF scientists have carried out research in the following areas of photocathode RF gun R&D:

- SDL Photoinjector commissioning: The photoinjector, designed and built by the ATF was successfully commissioned at the BNL SDL.
- Mg Cathode development: we have developed a reliable way manufacture Mg cathode for photocathode RF gun. A vacuum based laser cathode cleaning technique was developed at the ATF, demonstrating essentially 100% reliability and better than 10% electron emission uniformity over the cleaned area. A quantum efficiency (QE) of 0.2% was routinely measured over the past 18 moths, and a world record for a metal cathode QE of 0.5% was measured at the ATF.
- Longitudinal tomography was implemented at the ATF. Photoelectron beam longitudinal phase space dependency on the RF gun phase and charge was measured for the first time at the ATF.
- Preliminary design studies were performed at the BNL to develop a 120 Hz photocathode RF gun injection system for the X-ray SASE FEL project LCLS at SLAC. The design is based on the BNL gun IV; complete specifications for both RF gun and its laser system were developed based on our latest simulations.

As for ATF Operations, we provided more than 1000 hours for ATF users in the last year. In the continuous effort to improve ATF operations in a safe manner, we developed a BLOSA Training form suitable for ATF users updated the training procedures. A new water system was installed for gun solenoid magnet to improve the reliability of the system. The photocathode RF gun vacuum was improved to reach low 10^{-10} tor, a new laser oscillator was installed and a new modulator power supply.

The Staged Electron Laser Acceleration (STELLA) experiment, lead by Wayne Kimura (STI Optronics) and Arie van Steenbergen (BNL), was successful this past summer in one of the first demonstrations of staging between two laser accelerators. Here, two inverse free electron laser (IFEL) accelerators were driven by the ATF's high-power CO2 laser with the laser beam split into two separate beams driving each IFEL. The first IFEL pre-bunched the electrons into ~2-fs microbunches and the second IFEL accelerated these microbunches.

The drawing below shows the basic layout of the STELLA experiment.

A number of noteworthy accomplishments occurred during the STELLA program: 1) first demonstration of a laser-driven prebuncher staged together with a laser-driven accelerator; 2) first direct measurement of ~2-fs microbunches produced by a laser external to a wiggler; 3) first demonstration of acceleration of laser-generated microbunches with stable phase control maintained over periods of many minutes; and 4) first demonstration of laser-accelerated microbunches where a large portion of the electrons receive maximum energy gain.

Starting in 2001, during the next phase "STELLA-II", we plan to modify the IFELs in order to take advantage of the higher laser power (>300 GW near-term) that will be available from the upgraded ATF CO2 laser. The computer model predicts over 10 MeV energy gain in a tapered wiggler with >80% capturing of the electrons and an energy spread of ~1%.